Research Report
UKTRP-81-15

Identification, Analysis, and Correction of High-Accident Locations in Kentucky

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16. Abstract

The first step in the highway safety improvement process involves reporting and summarizing accidents by location. Once the high-accident locations are identified, field investigations and analysis follow. Locations are ranked on the basis of potential for accident reduction. Safety improvements are then scheduled and implemented. Finally, improvements are evaluated in terms of accident reduction.

This report compiles, in detail, the process involved in arriving at safety improvements in the high-accident spot-improvement program. References are made to information and methodologies developed in earlier reports by the Division of Research of the Kentucky Department of Transportation. Most of the background information and analysis techniques used to develop the methodologies are not included here. The methods, instead, are cited as they fit together in the total process. The procedures are shown as they fit into the total safety improvement process developed and implemented by the Division of Traffic of the Kentucky Department of Transportation.

17. Key Words

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Introduction

The process of improving highway safety on a statewide basis requires considerable engineering planning and judgment. In Kentucky, the state-maintained highway system consists of approximately 25,000 miles (40,000 km) of roads. Funds for safety improvements are available for all types of roads. The goal of the Kentucky Department of Transportation (KYDOT) is to improve safety of the highway system in such a way as to provide the greatest benefits to road-users. Methodologies have been developed for every step in the process of implementing safety improvements. The first step involves reporting and summarizing accidents by location. Once the high-accident locations are identified, field investigations and analyses follow. The locations are ranked on the basis of potential for reducing accidents. Safety improvements are then scheduled and implemented. Finally, improvements are evaluated in terms of accident reduction. A flow chart of the process is given in Figure 1.

The process of selecting safety improvements is compiled in detail in this report. References are made to information and methodologies developed in previous reports by the Division of Research of the KYDOT. Most of the background information and analyses reported before are not included here. The methods are fitted together into a total process implemented by the KYDOT Division of Traffic.

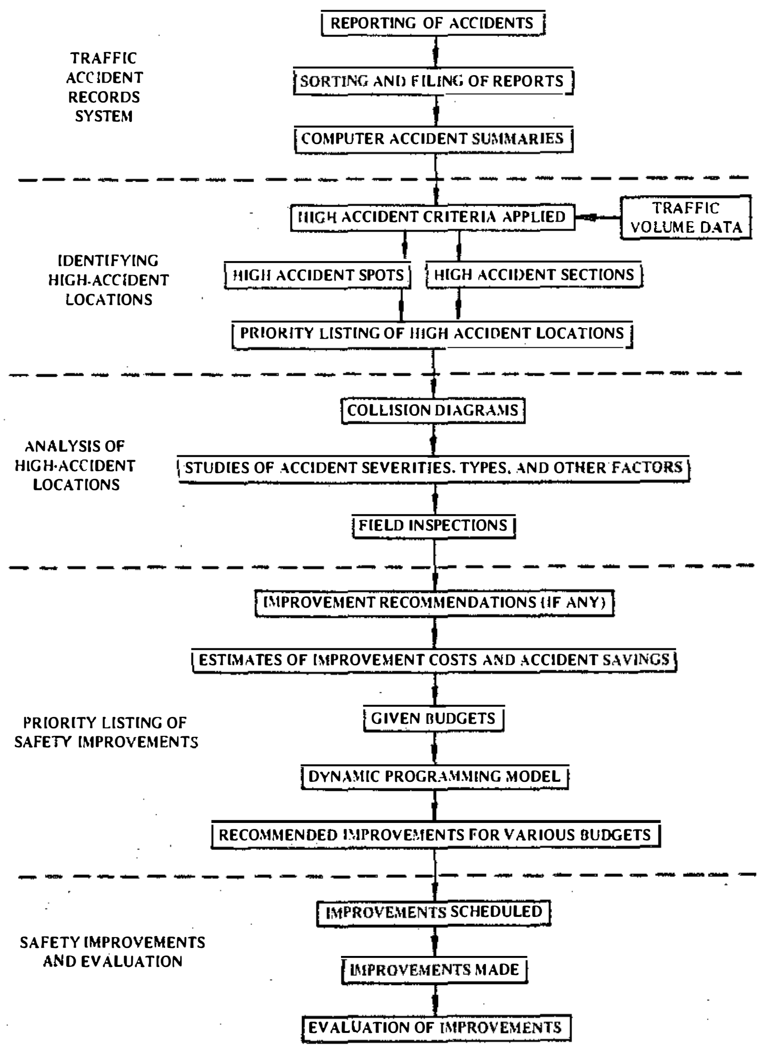


Figure 1. Chart of the highway safety improvement process.

Accident Reporting System

In 1976, the Kentucky Legislature enacted a law requiring copies of all reportable traffic accidents be sent to the state police headquarters in Frankfort. A reportable accident is one that involves at least $200 in property damage or an injury. A Uniform Accident Report (UAR) form was developed and is being used by all police agencies in Kentucky. The UAR form, as shown in Figure 2, provides information pertaining to the drivers and vehicles and a description of the accident. Space for an accident diagram and comments from the investigating officer is also provided. A cover sheet is also used (Figure 3). This is basically a code sheet for completing the report. Currently, about 150,000

UNIFORM POLICE TRAFFIC ACCIDENT REPORT

LOCAL CODE | AGENCY I.D. NO. | MASTER FILE NO.

INVESTIGATING AGENCY | KILLED | INJURED | INVESTIGATION COMPLETE ☐ INCOMPLETE ☐ | H. & R. | DAY | TIME | MO. | DAY | YEAR

TRAFFICWAY NO. OR NAME | MILES | N S | E W | IN OF | TOWN | COUNTY

1 INTERSECTION ☐ WITH OR BETWEEN STREETS ☐ ST. AND ST. | ___ FT. ___ MI. | N S | E W | MILE POST | OR PERMANENT LANDMARK REF. | SPEED LIMIT

2 UNIT 1 MTR. VEH. | REMOVED TO | NO. OCCU-PANTS | UNIT 2 VEH. OR PED. | REMOVED TO | NO. OCCU-PANTS

3 OPERATORS LIC. NO. | STATE | RESTRICTION ☐ NON-RESTRICTION ☐ | CODE | OPERATORS LIC. NO. | STATE | RESTRICTION ☐ NON-RESTRICTION ☐ | CODE

OPERATOR-LAST NAME | FIRST | M.I. | D.O.B. | OPERATOR-LAST NAME/PED. | FIRST | M.I. | D.O.B.

4 STREET NO. & NAME | CODE | STREET NO. & NAME | CODE

CITY | STATE | ZIP CODE | CITY | STATE | ZIP CODE

5 OWNER-LAST NAME | FIRST | OWNER-LAST NAME | FIRST

OWNER-ADDRESS | OWNER-ADDRESS

VEH. YEAR | MAKE | TYPE | STATE REGISTRATION NO. | YEAR | VEH. YEAR | MAKE | TYPE | STATE REGISTRATION NO. | YEAR

6 VEH. INS. CO. | VEH. INS. CO.

DAMAGED UNIT NUMBER ONE: TOP 9, BOTTOM 10; OTHER PROP. 1; NO DAMAGE 2; NON-FUNCTIONAL 3; FUNCTIONAL 4; DISABLING 5

1. REAR END | 2. OVERTAKING | LEFT TURN | INTERSECTION | 5 RIGHT TURN | 6 RIGHT TURN | 7 HEAD ON | 8 SIDE SWIPE

DAMAGED UNIT NUMBER TWO: TOP 9, BOTTOM 10; OTHER PROP. 1; NO DAMAGE 2; NON-FUNCTIONAL 3; FUNCTIONAL 4; DISABLING 5

7 INDICATE NORTH BY ARROW | ACCIDENT DESCRIPTION:

8

9

10

11

12

PROPERTY DAMAGE-OTHER THAN VEHICLES | OWNER | ADDRESS

1ST AID GIVEN BY: | INJURED OR DECEASED REMOVED BY: | REMOVED TO:

CHEM. TEST: YES ☐ OPER. #1 ☐ PED. ☐ NO ☐ OPER. #2 ☐ OTHER ☐ | TAKEN BY: | SENT TO: | RESULTS

DRIVERS/WITNESSES/PASSENGERS	ADDRESS	(IF DECEASED - DATE OF DEATH)	32	31	30	29	28	27	26	25

ENFORCEMENT ACTION ☐ #1 ☐ #2 | CITATION OR CASE NO.: | KRS NUMBER: | OFFENSE: | PHOTOS: ☐ YES ☐ NO PHOTOGRAPHER UNIT NO.___

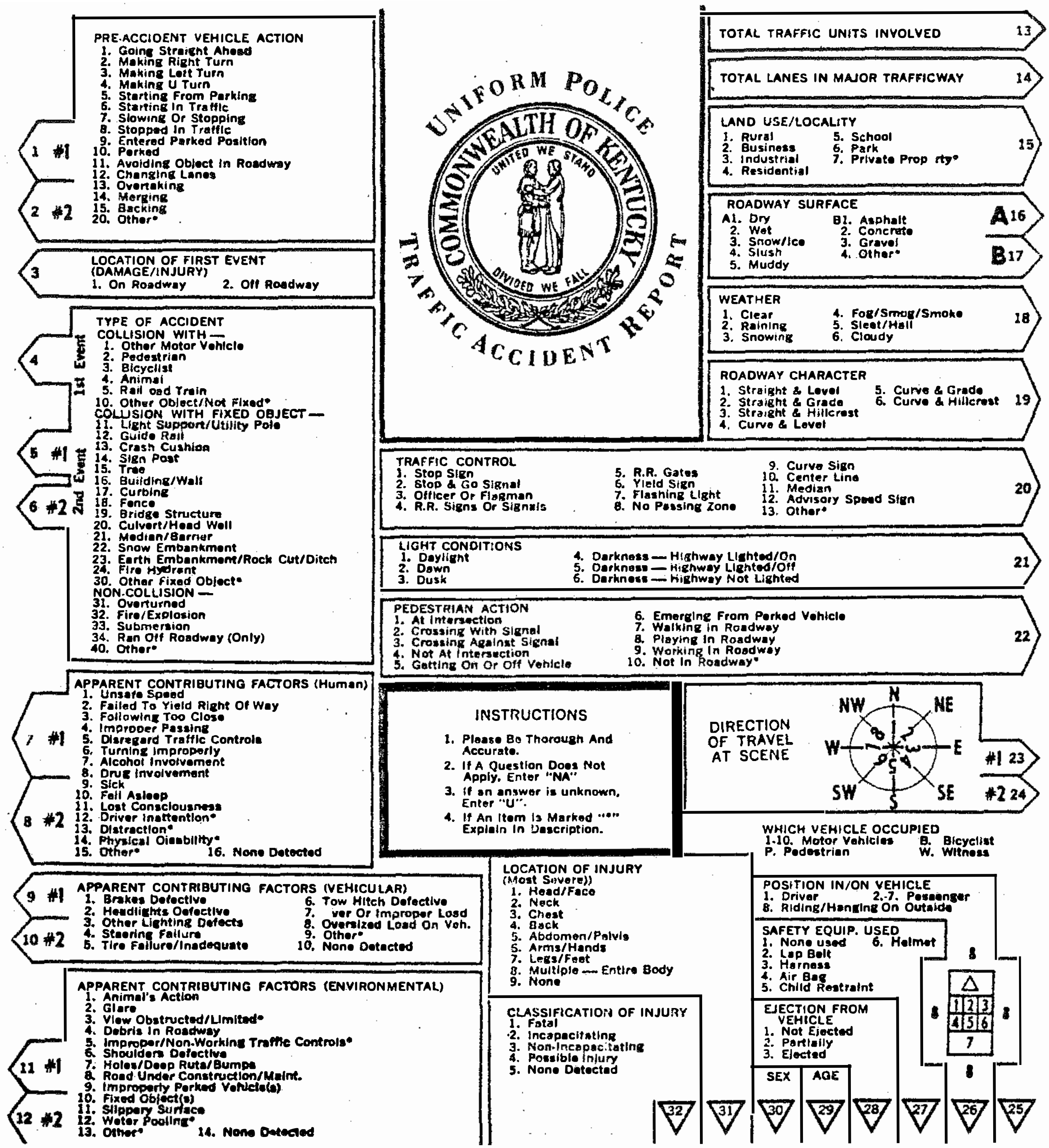
INVESTIGATOR | I.D. NO. | BEAT OR POST NO. | TIME NOTIFIED | TIME ARRIVED | SCENE CLEARED | REVIEWED BY: | PAGE OF PAGES

13 14 15 16 17 18 19 20 21 22 23 24

1 TRAFFIC RECORDS COPY (WITHIN TEN DAYS)

KSP 74 (1-79)

Figure 2. Kentucky uniform traffic accident report.



UNIFORM POLICE TRAFFIC ACCIDENT REPORT
COMMONWEALTH OF KENTUCKY
UNITED WE STAND DIVIDED WE FALL

PRE-ACCIDENT VEHICLE ACTION (1 #1, 2 #2)
1. Going Straight Ahead
2. Making Right Turn
3. Making Left Turn
4. Making U Turn
5. Starting From Parking
6. Starting In Traffic
7. Slowing Or Stopping
8. Stopped In Traffic
9. Entered Parked Position
10. Parked
11. Avoiding Object In Roadway
12. Changing Lanes
13. Overtaking
14. Merging
15. Backing
20. Other*

LOCATION OF FIRST EVENT (DAMAGE/INJURY) (3)
1. On Roadway 2. Off Roadway

TYPE OF ACCIDENT (4 1st Event; 5 #1, 6 #2 2nd Event)
COLLISION WITH —
1. Other Motor Vehicle
2. Pedestrian
3. Bicyclist
4. Animal
5. Railroad Train
10. Other Object/Not Fixed*
COLLISION WITH FIXED OBJECT —
11. Light Support/Utility Pole
12. Guide Rail
13. Crash Cushion
14. Sign Post
15. Tree
16. Building/Wall
17. Curbing
18. Fence
19. Bridge Structure
20. Culvert/Head Wall
21. Median/Barrier
22. Snow Embankment
23. Earth Embankment/Rock Cut/Ditch
24. Fire Hydrant
30. Other Fixed Object*
NON-COLLISION —
31. Overturned
32. Fire/Explosion
33. Submersion
34. Ran Off Roadway (Only)
40. Other*

APPARENT CONTRIBUTING FACTORS (Human) (7 #1, 8 #2)
1. Unsafe Speed
2. Failed To Yield Right Of Way
3. Following Too Close
4. Improper Passing
5. Disregard Traffic Controls
6. Turning Improperly
7. Alcohol Involvement
8. Drug Involvement
9. Sick
10. Fell Asleep
11. Lost Consciousness
12. Driver Inattention*
13. Distraction*
14. Physical Disability*
15. Other* 16. None Detected

APPARENT CONTRIBUTING FACTORS (VEHICULAR) (9 #1, 10 #2)
1. Brakes Defective
2. Headlights Defective
3. Other Lighting Defects
4. Steering Failure
5. Tire Failure/Inadequate
6. Tow Hitch Defective
7. Over Or Improper Load
8. Oversized Load On Veh.
9. Other*
10. None Detected

APPARENT CONTRIBUTING FACTORS (ENVIRONMENTAL) (11 #1, 12 #2)
1. Animal's Action
2. Glare
3. View Obstructed/Limited*
4. Debris In Roadway
5. Improper/Non-Working Traffic Controls*
6. Shoulders Defective
7. Holes/Deep Ruts/Bumps
8. Road Under Construction/Maint.
9. Improperly Parked Vehicle(s)
10. Fixed Object(s)
11. Slippery Surface
12. Water Pooling*
13. Other* 14. None Detected

TOTAL TRAFFIC UNITS INVOLVED 13

TOTAL LANES IN MAJOR TRAFFICWAY 14

LAND USE/LOCALITY 15
1. Rural
2. Business
3. Industrial
4. Residential
5. School
6. Park
7. Private Property*

ROADWAY SURFACE A 16, B 17
A1. Dry
2. Wet
3. Snow/Ice
4. Slush
5. Muddy
B1. Asphalt
2. Concrete
3. Gravel
4. Other*

WEATHER 18
1. Clear
2. Raining
3. Snowing
4. Fog/Smog/Smoke
5. Sleet/Hail
6. Cloudy

ROADWAY CHARACTER 19
1. Straight & Level
2. Straight & Grade
3. Straight & Hillcrest
4. Curve & Level
5. Curve & Grade
6. Curve & Hillcrest

TRAFFIC CONTROL 20
1. Stop Sign
2. Stop & Go Signal
3. Officer Or Flagman
4. R.R. Signs Or Signals
5. R.R. Gates
6. Yield Sign
7. Flashing Light
8. No Passing Zone
9. Curve Sign
10. Center Line
11. Median
12. Advisory Speed Sign
13. Other*

LIGHT CONDITIONS 21
1. Daylight
2. Dawn
3. Dusk
4. Darkness — Highway Lighted/On
5. Darkness — Highway Lighted/Off
6. Darkness — Highway Not Lighted

PEDESTRIAN ACTION 22
1. At Intersection
2. Crossing With Signal
3. Crossing Against Signal
4. Not At Intersection
5. Getting On Or Off Vehicle
6. Emerging From Parked Vehicle
7. Walking In Roadway
8. Playing In Roadway
9. Working In Roadway
10. Not In Roadway*

INSTRUCTIONS
1. Please Be Thorough And Accurate.
2. If A Question Does Not Apply, Enter "NA"
3. If an answer is unknown, Enter "U".
4. If An Item Is Marked "*" Explain In Description.

DIRECTION OF TRAVEL AT SCENE (#1 23, #2 24)
N NE E SE S SW W NW

WHICH VEHICLE OCCUPIED
1-10. Motor Vehicles
P. Pedestrian
B. Bicyclist
W. Witness

LOCATION OF INJURY (Most Severe)
1. Head/Face
2. Neck
3. Chest
4. Back
5. Abdomen/Pelvis
6. Arms/Hands
7. Legs/Feet
8. Multiple — Entire Body
9. None

POSITION IN/ON VEHICLE
1. Driver 2.-7. Passenger
8. Riding/Hanging On Outside

SAFETY EQUIP. USED
1. None used
2. Lap Belt
3. Harness
4. Air Bag
5. Child Restraint
6. Helmet

EJECTION FROM VEHICLE
1. Not Ejected
2. Partially
3. Ejected

CLASSIFICATION OF INJURY
1. Fatal
2. Incapacitating
3. Non-Incapacitating
4. Possible Injury
5. None Detected

SEX AGE

32 31 30 29 28 27 26 25

Figure 3. Kentucky uniform traffic accident report cover sheet.

accidents are reported annually.

After accident reports are received by State Police, they are processed by their Division of Traffic Records. Later, they are sent to the Division of Traffic, Department of Transportation, where location information is verified and added. Reports are then returned to the Data Processing Center of State Police for coding and storage of all pertinent accident information on computer tape. Copies of the tape are provided to various agencies, including the Department of Transportation.

Information taken from the UAR form includes over 1,000 numerical columns for each accident. An example of coded information that is useful to the traffic engineer is the directional analysis used to prepare collision diagrams and to perform other types of analysis. A revision of this code was adopted, beginning January 1, 1980, to give more detailed information about each accident. Accidents are classified and coded according to Table 1. The major categories include intersection, nonintersection (roadway sections and midblock, and bridge), interchange ramp, and miscellaneous accident types.

The distribution and use of computerized information is monitored for the Department of Transportation by the Office of Highway Safety. To aid the processing and summarizing of approximately 150,000 accident reports annually, the Kentucky Accident Reporting System (KARS) was developed. The KARS periodically generates reports such as detailed listings of accidents by location, contributing environmental factors, highway system, and rural-urban designation. A unique feature of KARS includes summary reports for 11 jurisdictions such as highway district, police district, area development district, etc. A statewide traffic volume file, created by the Divisions of Research and Traffic is being used in combination with KARS to compute accident rates. A summary of the reporting features available through KARS is given in APPENDIX A.

As an aid in the analysis of accident records, the Office of Highway Safety also maintains the "Records Analysis for Problem Identification and Definition (RAPID)" software package. This package provides a means of obtaining summaries of the accident data for a large number of variables. In-depth summaries of accident data can be obtained using the RAPID programs. A list of the variables available through RAPID is given in APPENDIX B. Also included in RAPID are an Area Identification Module (AIM), which can be used to find and analyze high accident locations, and an Area Criticality Technique (ACT), which can determine priorities among political subdivisions.

Table 1. Directional Analysis Codes (Revised 1/1/80).

00 NOT STATED

I. INTERSECTION ACCIDENTS

01 ANGLE ACCIDENT - BOTH VEHICLES GOING STRAIGHT
02 ANGLE ACCIDENT - ONE VEHICLE TURNING LEFT
03 ANGLE ACCIDENT - ONE VEHICLE TURNING RIGHT
04 ANGLE ACCIDENT - OTHER
05 REAR END - ONE VEHICLE STOPPED
06 REAR END - BOTH VEHICLES GOING STRAIGHT
07 REAR END - ONE VEHICLE TURNING LEFT
08 REAR END - ONE VEHICLE TURNING RIGHT
09 REAR END - OTHER
10 OPPOSITE DIRECTIONS - ONE VEHICLE TURNING LEFT, ONE GOING STRAIGHT
11 OPPOSITE DIRECTIONS - BOTH VEHICLES GOING STRAIGHT
12 OPPOSITE DIRECTIONS - OTHER
13 COLLISION WITH A FIXED OBJECT (SINGLE VEHICLE)
14 NON-COLLISION ACCIDENT (SINGLE VEHICLE)

Table 1. Directional Analysis Codes (Revised 1/1/80) (*continued*).

15	COLLISION WITH A PEDESTRIAN
16	COLLISION WITH A BICYCLE
17	VEHICLE BACKING
18	COLLISION WITH A NON-FIXED OBJECT OR ANIMAL
19	SAME DIRECTION - SIDESWIPE
20	OTHER INTERSECTION ACCIDENTS

II. NON-INTERSECTION ACCIDENTS

ROADWAY SECTIONS AND MID-BLOCK

24	REAR END IN TRAFFIC LANE - ONE VEHICLE STOPPED
25	REAR END IN TRAFFIC LANE - BOTH VEHICLES MOVING
26	REAR END ON SHOULDER
27	OTHER ACCIDENTS ON SHOULDER
28	HEAD ON COLLISION
29	SIDESWIPE ACCIDENT - SAME DIRECTION
30	SIDESWIPE ACCIDENT - OPPOSITE DIRECTION
31	ONE VEHICLE ENTERING OR LEAVING A PRIVATE DRIVEWAY
32	ONE VEHICLE ENTERING OR LEAVING AN ALLEY OR PUBLIC ENTRANCE
33	ONE VEHICLE ENTERING PARKED POSITION (NOT IN A PARKING LOT)
34	ONE VEHICLE LEAVING PARKED POSITION (NOT IN A PARKING LOT)
35	ONE VEHICLE IN PARKED POSITION (NOT IN A PARKING LOT)
36	MEDIAN CROSS-OVER ACCIDENT
37	VEHICLE GOING IN WRONG DIRECTION
38	COLLISION WITH A PEDESTRIAN
39	COLLISION WITH A BICYCLE
40	COLLISION WITH A FIXED OBJECT (SINGLE VEHICLE)
41	COLLISION WITH A NON-FIXED OBJECT (SINGLE VEHICLE)
42	COLLISION WITH AN ANIMAL OR BIRD (SINGLE VEHICLE)
43	RAN OFF ROADWAY (SINGLE VEHICLE)
44	OVERTURNED IN ROADWAY (SINGLE VEHICLE)
45	OCCUPANT FELL FROM MOVING VEHICLE
46	OTHER ROADWAY OR MID-BLOCK ACCIDENT

BRIDGE RELATED ACCIDENTS

51	COLLISION WITH APPROACH GUARDRAIL
52	GAP BETWEEN BRIDGES
53	COLLISION WITH ABUTMENT
54	COLLISION WITH BRIDGE RAIL OR CURB
55	WENT THROUGH OR OVER BRIDGE RAIL
56	REAR END
57	HEAD-ON
58	SIDESWIPE - OPPOSITE DIRECTIONS
59	SIDESWIPE - SAME DIRECTION
60	RAN OFF ROAD AFTER LOSING CONTROL ON BRIDGE
61	OTHER BRIDGE RELATED ACCIDENTS

Table 1. Directional Analysis Codes (Revised 1/1/80) (*continued*).

III. INTERCHANGE RAMP ACCIDENTS	
65	COLLISION WITH A FIXED OBJECT IN GORE (SINGLE VEHICLE)
66	COLLISION WITH A FIXED OBJECT NOT IN GORE (SINGLE VEHICLE)
67	RAMP VEHICLE RAN OFF ROADWAY (SINGLE VEHICLE)
68	OVERTURNED ON RAMP (SINGLE VEHICLE)
69	OTHER SINGLE VEHICLE ACCIDENTS
70	REAR END - WHILE GETTING ON RAMP
71	REAR END - WHILE ON RAMP
72	REAR END - WHILE LEAVING RAMP
73	OTHER MULTIPLE VEHICLE ACCIDENTS - WHILE GETTING ON RAMP
74	OTHER MULTIPLE VEHICLE ACCIDENTS - WHILE ON RAMP
75	OTHER MULTIPLE VEHICLE ACCIDENTS - WHILE LEAVING RAMP
76	OTHER RAMP RELATED ACCIDENTS
IV. MISCELLANEOUS ACCIDENTS	
90	ACCIDENTS IN PARKING LOTS
91	COLLISION WITH A TRAIN
92	OTHER RAILROAD CROSSING RELATED ACCIDENTS
93	COLLISION WITH A TOLL BOOTH
94	OTHER TOLL BOOTH RELATED ACCIDENTS
95	ALL OTHER ACCIDENTS

Accident Location Systems

The location of each accident must be referenced accurately to a known point or marker. Location descriptors generally in use are variations of three basic concepts (1):

1. route-mileage system (milepoint or reference point systems),
2. link-node system, and
3. coordinate system.

Route-mileage systems are based on milepoints or reference points. In both cases, the county and route numbers are usually given first, followed by the milepost or reference number. Mileposting begins and ends at a boundary such as county or state line, or the beginning or ending of a route. Mileposts are placed at regular intervals (such as every mile) along the highway so police officers record accidents by referencing them. Reference point systems consist of numbering landmarks along a road. Such features would include bridges, overpasses, creeks, and railroad crossings. Each system has certain advantages and disadvantages in terms of accuracy and clarity (1). Both are suited for use in rural areas.

Link-node or "nodal" systems involve assigning numbers to intersections and other points such as railroad crossings. An accident site is then located in terms of a distance from a node along a link. In some cases, numbers are assigned to each link, and an intersection is represented by the combination of two link numbers. Nodal systems are particularly applicable in urban areas where intersections are close together (1).

Coordinate systems describe a point along a road in terms of X and Y coordinates. Such systems are most applicable in states where rectangular boundary lines are common and where roads are generally in a rectangular configuration. Such a system may be applied best in rural areas where streets are not close together. Confusion may result in urban areas with closely spaced streets (1). An example of a coordinate system is the LORAN-C System, which uses radio signals to locate accidents. This system has been tested in Kentucky.

At the present time, the milepoint system is used in Kentucky to locate accidents in rural areas. The milepoints increase from the southern or western boundary (county or state lines) of a route or from the beginning point of the route if it does not cross such boundaries (1). The mileposts are generally spaced at 1-mile (1.601-km) intervals. In urban areas, mileposts are given for many accidents, but street names are also given. A large number of accidents, particularly in urban areas, occur on non-state-maintained streets where mileposts have not been placed. A link-node system is under study for implementation to improve reporting accuracy in urban areas. Jefferson and Shelby Counties were selected for trial implementation. Implementation of such a system would greatly enhance present accident location capabilities.

Identifying Hazardous Locations

Norms and Criteria

To identify hazardous locations on a wide basis, accident data and traffic volumes must be available. The procedure should take into account the type of area (rural or urban), historical trends (a few months or years), length of the site, and the type of highway (two-lane, interstate, four-lane, etc.). Questions include: What size of accident data base should be used? How much weight should be given to fatal and injury accidents compared to property-damage-only (PDO) accidents? What form of priority listing should be used to select locations for future investigation? These and many other questions have been answered for Kentucky. A methodology has been developed to identify hazardous spots and sections in urban and rural areas, and to rank them in priority order for correction. Some background information and definitions are presented:

Spot -- A specific, identifiable point on a highway. In rural areas of Kentucky, a spot is defined as a 0.3-mile (0.48-km) segment because the cause and result of an accident may encompass that distance. Also, a slight error in reporting accidents may result in variations of at least 0.1 mile (0.16 km) on either side of a stated point. Accidents occurring within about 200 feet (61 m) of an intersection on any approach are usually identified as an intersection spot (2, 3, 4).

Section -- A length of highway or street with relatively homogeneous characteristics is considered a section. The length of a section may vary, but it is greater than 0.3 mile (0.48 km). Sections are often identified as 1.0-mile and 3.0-mile (1.6-km and 4.8-km) segments. However, uneven section lengths are also studied (2, 3, 4).

Intersection -- The crossing of two major streets or highways defines an intersection for purposes of accident analysis. The intersection includes up to 200 feet (61 m) on all approaches. Intersections are identified by the two streets or route numbers.

Midblock -- Midblock is considered to be a spot in an urban area. It is located by the street on which the accident occurs and the two adjacent cross-streets.

Criteria for identifying hazardous locations are based on frequency of accidents, rates, severities, or any combinations thereof. The five most commonly used methods are:

1. accident frequency,
2. accident-rate,
3. frequency-rate,
4. rate-quality control, and
5. accident severity.

The essential and basic types of data include the following:

Time Period -- Time periods of one and two years have been used in Kentucky. The one-year period helps to select locations that become hazardous, and the two-year period provides the desired data stability

(3). However, a one-year period has been used most often in Kentucky because of ease in handling accident data.

Accident Locations -- Accidents on posted routes in rural and urban areas are reported to the nearest 0.1-milepost. In urban or rural areas where mileposts are not available, intersection accidents are located in terms of the two intersecting streets or highways. Where a node system is used, the intersection node number would be used. Midblock accidents should be reported by the street where the accident occurred and the intersecting streets on both ends. Distance from the nearest intersection is also useful for better accuracy.

Section Lengths -- Any section length may be used for routine searches through the accident tape. Section lengths of 1.0 and 2.0 miles (1.6 and 3.2 km) are commonly used. Spot lengths in rural areas are 0.3 mile (0.48 km).

Traffic Volumes -- Average annual daily traffic (AADT) volumes must be available for calculation of accident rates.

Highway Type -- In some identification methods, comparisons are made by type of highway. The highway categories used in Kentucky are:

Urban Areas (Two Alternatives)

- Two-lane
- Four-lane Divided
- Four-lane Undivided
- Interstate
- Parkway

or

- Local Streets
- Arterial-Collectors
- Freeways

Rural Areas

- One-lane
- Two-lane
- Four-lane Divided
- Four-lane Undivided
- Interstate
- Parkways

Data requirements for each method are given in Table 2 (2, 4). These data requirements include time period, accident

Table 2. Data Requirements for Various Methods of Location Identification.

DATA REQUIREMENTS	METHOD USED				
	NUMBER OF ACCIDENTS	ACCIDENT RATE	NUMBER RATE	RATE-QUALITY CONTROL	SEVERITY
TIME PERIOD	X	X	X	X	X
ACCIDENT LOCATIONS	X	X	X	X	X
SECTION LENGTHS		X	X	X	X
TRAFFIC VOLUMES		X	X	X	
AVERAGE ACCIDENT RATES		X	X	X	
CATEGORIES OF HIGHWAYS			X	X	X

locations, section lengths, traffic volumes, average accident rates, and highway categories. All of the data are needed for the rate-quality control and frequency-rate methods. Highway categories are not necessary for the accident-rate method, and the frequency method requires only a time period and a listing of accident locations.

Criteria requirements for each method are shown in Table 3. For highway sections, the criteria are accidents per mile (1.6 km) and accidents per 100 million vehicle - miles (160 million vehicle-kilometers). For intersections and spots, number of accidents and accidents per million vehicles are used.

Following is a description of the basic methods used for identifying high-accident locations:

Frequency of Accidents Method -- The frequency method is the simplest and most direct. It considers only frequencies of accidents per spot or section of highway. Locations and sections with more than a predetermined number of accidents are classified as high-accident locations (5). This method is best used for street systems of small towns, local street systems of larger cities, and low-volume county roads.

The primary deficiency in using only this method is the lack of consideration for traffic volume and accident severity (2, 6). The frequency method is often used by states to select an initial set of locations, and then those locations are ranked in priority by some other method. Accident spot maps are often used to graphically plot accidents by location.

Accident-Rate Method -- This method involves calculation of accident rates for all spots and sections under consideration. Accident numbers are divided by vehicle exposure to give rates in terms of accidents per million vehicles (spots) or accidents per 100 million vehicle-miles (160 million vehicle-kilometers) (sections). Locations with rates exceeding predetermined levels are classified as high-accident locations (5).

To apply the rate method, traffic volumes must be known for all locations and sections under study. This method poses problems when locations with wide ranges of volumes are compared. For example, locations with an AADT of 100 or less will have a very high rate even when one accident occurred per year. A location with an AADT of 10,000 must have a very large number of accidents to have an equal accident rate.

The equation for accident rate for a

Table 3. Criteria Requirements for Methods of Identifying Hazardous Locations.

CRITERIA MEASUREMENT UNITS	METHOD USED				
	NUMBER OF ACCIDENTS	ACCIDENT RATE	NUMBER RATE	RATE-QUALITY CONTROL	SEVERITY
SECTIONS					
ACCIDENTS PER MILE			X		
ACCIDENTS PER 100 MVM		X	X	X	
INTERSECTIONS & SPOTS					
NUMBER OF ACCIDENTS	X		X		
ACCIDENTS PER MV		X	X	X	
ACCIDENT SEVERITY					X

spot location is as follows:

$$R = (A)(1,000,000)/365(T)(V) \quad (1)$$

in which R = accident rate at a spot in accidents per million vehicles,
A = number of accidents for study period,
T = period of study (years or fraction of years), and
V = AADT during the study period (for intersections, the sum of the entering volumes on all approach legs).

For roadway sections, length becomes a consideration, and the equation becomes (2):

$$R = (A)(1,000,000)/(365)(T)(V)(L) \quad (2)$$

in which R = accident rate on the section in accidents per 100 million vehicle-miles (160 million vehicle-kilometers), and
L = length of the roadway section (miles (1.6 kilometers)).

<u>Frequency-Rate</u> <u>Method</u> -- The frequency-rate method is normally applied by first selecting a large sample of high-accident locations. Accident rates are computed for those locations selected on the basis of accident frequency. This method eliminates the need to calculate accident rates for every location in the state. It also eliminates the low-volume locations with only one or two accidents per year.

This method provides greater reliability than either the frequency method or the rate method because locations must exceed criteria for both frequencies and rates. However, after the list of locations is selected using this method, there is still a problem with the ranking procedure. The low-volume locations will still tend to be ranked higher than the high-volume locations because accident rates are used for priority ranking.

<u>Rate-Quality</u> <u>Control</u> <u>Method</u> -- A variation of the rate method is the rate-quality control method. It utilizes a statistical test to determine whether the accident rate at a particular location is abnormally high compared to a predetermined average rate for locations having similar characteristics (3). The statistical tests are based on the commonly accepted assumption that accidents approximate the Poisson distribution. In this method, the accident rate at a location is compared to a critical rate, which is based on volume, average rate, and a statistical constant.

The equation for calculating the critical rate for a spot is as follows (3, 7, 8):

$$Rc = Ra + (K)SQRT(Ra/M) + 1/2M \quad (3)$$

in which Rc = critical accident rate for a spot (accidents per million vehicles),
Ra = average accident rate for all spots of similar characteristics or on similar road types (accidents per million vehicles),
M = millions of vehicles passing over a spot in the study period, and
K = a probability determined by the desired level of significance for the equation.

When highway sections are considered instead of spots, the values of Rc, Ra, and M are expressed in terms of 100 million vehicle-miles (160 million vehicle-kilometers). Any time period or section length (preferably 1.0 mile (1.6 km) or above) can be used in the equation.

The K value is determined by the level of probability, P, that an accident rate is sufficiently large that it cannot be reasonably attributed to random occurrences. The primary determinant of the constant, K, is the number of hazardous locations that can be handled. Selected values of K are (3):

P	.995	.975	.950	.925	.900
K	2.576	1.960	1.645	1.440	1.282

The most commonly used K values are 2.576 (P = 0.995) and 1.645 (P = 0.950).

<u>Severity</u> <u>Method</u> -- There are numerous severity methods used in different states to identify and prioritize high-accident locations. Some states consider only injury and fatality accidents to identify locations and sections. Other states apply weighting factors to accidents based on severity and compute some form of severity index or severity number. Locations are then

ranked by the severity index or number.

Accident severities often are classified into five categories, depending on extent of injury, as follows (9):

fatal accident - involves a fatality,

A-type injury accident -- includes an injury that involves a bleeding wound, distorted member, or a person carried from scene,

B-type injury accident -- includes an injury involving bruises, abrasions, swelling, or limping,

C-type injury accident -- accident in which no visible injuries occur but in which there are complaints of pain, and

PDO accident -- property-damage-only accident.

One of the more widely used severity indices is the equivalent-property-damage-only method (EPDO method). The formula used to calculate EPDO may vary among states and in Kentucky is as follows (9):

$$EPDO = 9.5(F + A) + 3.5(B + C) + PDO, \quad (4)$$

in which EPDO = number of equivalent property-damage-only, (PDO) accidents,

F = number of fatal accidents,

A = number of A-type injury accidents,

B = number of B-type injury accidents,

C = number of C-type injury accidents, and

PDO = number of PDO accidents.

In this equation, each accident is classified as to the most severe injury, and an accident is counted only once. The highest possible EPDO value is 9.5. This would occur if all accidents were fatal or A-type injury accidents. The lowest possible EPDO at an accident location is 1.0. This would occur if all accidents were PDO accidents.

Procedure for Rural Highways

The basic procedure for identifying high-accident locations on Kentucky's rural highways was first developed in 1974 (3) and has remained the same; accident rates, however, have been updated. The frequency criterion is used to scan the accident tape and select spots and sections which exceed the norm. The norm for 0.3-mile (0.48-km) spots originally recommended was 5 accidents per year or 7 accidents in two years. For 1.0-mile (1.6-km) sections, this was 10 accidents per year or 15 accidents in two years. For 3.0-mile (4.8-km) sections, the criteria was 20 accidents per year or 30 accidents in two years (3). These norms were based on 1970-1972 data (10). Recently, average and critical frequencies of accidents were developed for 0.3-mile (0.48-km) spots and 1.0-mile (1.6-km) sections (for various types of highways) using 1978 accident data (11). The results for rural and urban highways are shown in Table 4. Curves giving the critical frequencies for section lengths

Table 4. Statewide Average and Critical Number of Accidents by Highway Classification (1978 Data).

AREA	HIGHWAY	ACCIDENTS PER 0.3-MILE (0.48 KM) SPOT AVERAGE	ACCIDENTS PER 0.3-MILE (0.48 KM) SPOT CRITICAL NUMBER	ACCIDENTS PER 1.0-MILE (1.6 KM) SECTION AVERAGE	ACCIDENTS PER 1.0-MILE (1.6 KM) SECTION CRITICAL NUMBER
RURAL	ONE-LANE	.10	2	.33	3
	TWO-LANE	.42	3	1.41	5
	FOUR-LANE, DIVIDED (NO ACCESS CONTROL)	1.90	6	6.32	14
	FOUR-LANE, UNDIVIDED	3.76	10	12.51	22
	INTERSTATE	1.32	5	4.41	11
	PARKWAY	.33	3	1.11	5
URBAN	TWO-LANE	5.52	12	18.40	30
	FOUR-LANE, DIVIDED (NO ACCESS CONTROL)	13.47	24	44.86	63
	FOUR-LANE, UNDIVIDED	17.57	29	58.60	79
	INTERSTATE	10.55	20	35.20	51
	PARKWAY	.54	3	1.79	6

Table 5. Accident Rates for Spots and Sections for Various Types of Rural Highway (1970-1972 Data).

HIGHWAY	AVERAGE STATEWIDE ACCIDENT RATES: SPOTS (ACCIDENTS PER MILLION VEHICLES)	AVERAGE STATEWIDE ACCIDENT RATES: SECTIONS (ACCIDENTS PER 100 MILLION VEHICLE MILES)
TWO- AND THREE- LANE	0.72	240
FOUR-LANE UNDIVIDED	0.94	313
FOUR-LANE DIVIDED	0.47	156
INTERSTATE AND PARKWAY	0.25	84

up to 20 miles (32 km) are given in APPENDIX C. The spots and sections qualifying (Table 4) are then tested by the rate-quality control method and the EPDO method. Locations must meet at least one of the criteria developed for these two methods to be eligible for field inspection (3).

The rate-quality control method first considers the type of highway on which each spot or section is located. The statewide average rates originally used in the analysis are given in Table 5 (10). Those rates were based on 1970 through 1972 data and have been updated using 1978 data (11). The rates were similar for some types of highways but increased among others. The differences in rates may be attributed to improved accident reporting rather than real increases in accident rates. These updated values are shown in Table 6 (Ra values used in Equation 3). Interstates had the lowest rates for sections (69 accidents per 100 million vehicle-miles (160 million vehicle-kilometers); parkways had 84 accidents per 100 million vehicle-miles (160 million vehicle-kilometers). The highest rate was 357 for four-lane, undivided highways.

The critical rates for spots, as calculated using Equation 3, are shown in Figures 4 and 5. The curves are for spots

Table 6. Updated Accident Rates for Spots and Sections of Rural Highways (1978 Accident Data).

	AVERAGE STATEWIDE ACCIDENT RATES: SPOTS (ACCIDENTS PER MILLION VEHICLES)	AVERAGE STATEWIDE ACCIDENT RATES: SECTIONS (ACCIDENTS PER 100 MILLION VEHICLE MILES)
ONE-LANE	1.03	347
TWO-LANE*	0.93	311
FOUR-LANE DIVIDED (NO ACCESS CONTROL)	0.55	184
FOUR-LANE UNDIVIDED	1.06	357
INTERSTATE	0.21	69
PARKWAY	0.25	84

* THREE-LANE ROADS HAD A VERY SMALL SAMPLE, SO THEY SHOULD BE INCLUDED IN THE TWO-LANE CATEGORY.

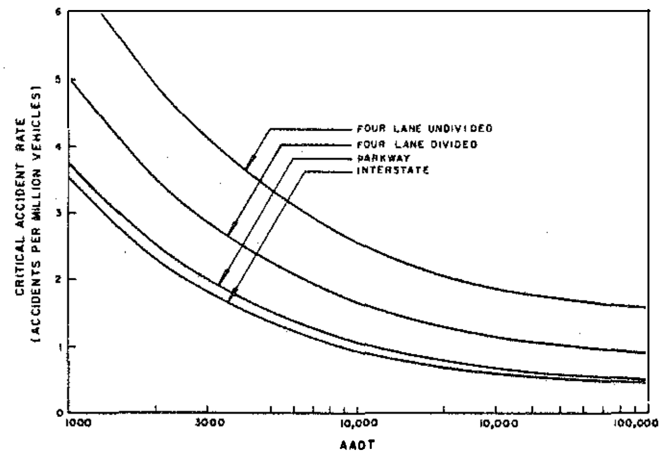


Figure 4. Critical accident rates for 0.3-mile (0.48-km) spots on rural, multilane highways (one-year data) (P = 99.5).

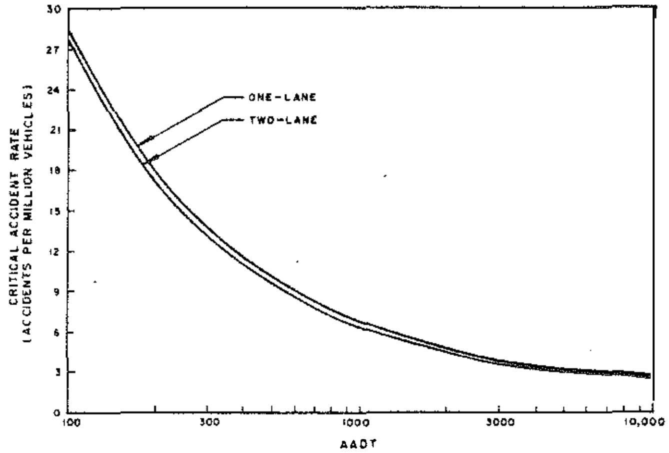


Figure 5. Critical accident rates for 0.3-mile (0.48-km) spots on rural, one- and two-lane roads (one-year data) (P=99.5)

and are based on one year of data. A probability level of 0.995 was used.

The critical rate for sections was also computed using the rate-quality control formula (Equation 3). A graphical illustration of critical rates on two-lane highways using one year of accident data is shown in Figure 6 (3). A separate curve is given for section lengths of 1.0 mile (1.6 km) to 20 miles (32 km). As section length increases, the sample is larger, and scatter is reduced; thus, critical rates are lower. Curves are presented for AADT values of 100 to 10,000. Critical-rate curves for other types of highways are given in APPENDIX D (3).

After the critical rates are determined, rates are computed (Equations 1 and 2). To rank spots and sections, the critical rate factor of each location is found by the formula:

$$CRF = R/Rc \qquad (5)$$

in which CRF = critical rate factor,

R = accident rate, and

Rc = critical rate.

A location is critical when the rate factor is 1.0 or more. This means that the rate equals or exceeds the critical rate. Separate priority listings are normally made for spots and sections.

For locations that meet the frequency criteria but do not have critical rates, the EPDO value is also checked. The criteria recommended in the original report for spots were an EPDO of 12.5 for a one-year period or 21.5 for a two-year period. For 1.0-mile (1.6-km) sections, the EPDO criteria were 25 for one year or 40 for two years. For 3.0-mile (4.8-km) sections, the EPDO criteria were 50 for one year or 75 for two years. The updated (1978) values for rural and urban highways are shown in Table 7 (11). Curves giving the critical EPDO for section lengths up to 20 miles (32 km) are given in APPENDIX C.

The source deck for the computer program which determines high-accident locations is given in APPENDIX E. The procedure described here applies to highways posted with route markers and mileposts. A matching process is used to identify high-accident locations on other highways. A frequency cutoff is selected and roads with more accidents than the cutoff value are listed. The procedure does not consider length of the roadway,

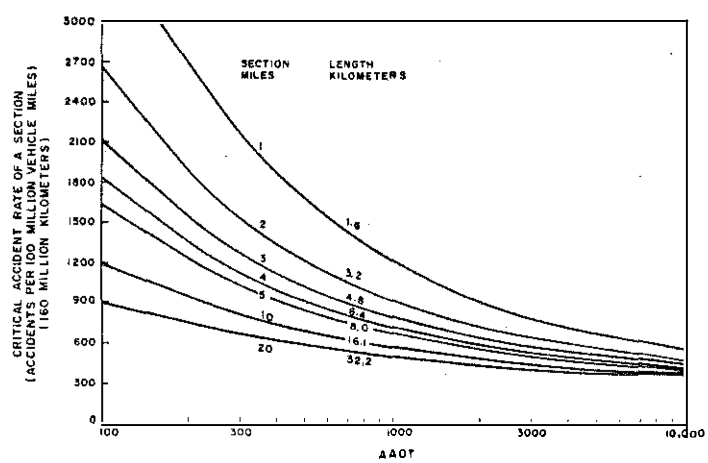


Figure 6. Critical accident rates for rural, two-lane, highway sections (one-year data) (P = 99.5).

Table 7. Statewide Average and Critical Number of EPDO Accidents by Highway Classification (1978 Data).

AREA	HIGHWAY	EPDO ACCIDENTS PER 0.3-MILE (0.48-KM) SPOT		EPDO ACCIDENTS PER 1.0-MILE (1.6-KM) SECTION	
		AVERAGE	CRITICAL NUMBER	AVERAGE	CRITICAL NUMBER
RURAL	ONE-LANE	.24	2	.81	4
	TWO-LANE	1.02	5	3.39	9
	FOUR-LANE, DIVIDED (NO ACCESS CONTROL)	4.76	11	15.88	27
	FOUR-LANE, UNDIVIDED	8.13	16	27.32	41
	INTERSTATE	3.30	9	10.99	20
	PARKWAY	.82	4	2.79	8
URBAN	TWO-LANE	9.57	18	31.86	47
	FOUR-LANE, DIVIDED (NO ACESSS CONTROL)	23.94	37	79.70	104
	FOUR-LANE, UNDIVIDED	29.53	44	95.54	122
	INTERSTATE	19.45	32	64.90	87
	PARKWAY	1.05	5	3.44	9

and it depends on road names being spelled correctly.

Procedures for City Streets

The original procedure for identifying hazardous locations on city streets was developed in 1975 (12). The procedure basically used the frequency criteria and the rate-quality control method for intersections and midblocks on arterial-collector streets. Freeway sections were also identified. Local streets were not included. However, it became evident this method of identifying urban locations by intersection or midblock and population group would not be the most efficient method under the current information storage format. Since a uniform accident reporting law has been implemented, both rural and urban accident data became available on computer tape. Therefore, when the rural accident rates were updated with 1978 data, rates were also calculated for urban locations (11). It was then possible to identify hazardous locations on urban streets using the same method as for rural highways. While this procedure is being used for urban areas, the original procedure provides an alternate method. A summary of that methodology follows.

<u>Original Urban Procedure</u> -- Cities with over 2,500 population were considered urban areas (12). The 1975 study identified 97 such cities. For cities in each population group, the average frequency of midblock and intersection accidents on arterial and collector streets were determined. Based on these averages, the critical frequency of accidents for each location was determined

based on a form of the rate-quality control formula. These critical frequencies were the criteria used initially to identify high-accident locations. For intersections, the criteria for a one-year period ranged from 19 (Group 1 cities; population over 200,000) to 4 accidents (Group 6 cities, population 2,500 to 5,000). After the midblocks and intersections were identified based on frequencies, the rate-quality control formula was applied. Average rates for midblocks and intersections on arterial-collector streets for each city size were determined. In a report identifying problem areas for Kentucky's Highway Safety Plan, rates by population category were calculated and cities with rates above critical were identified (13). The 1978 accident analysis also provided rates for several cities (11). For urban freeway sections, average and critical frequencies were determined. Critical rate curves were determined for cities containing freeways in two population groups. All sections, midblocks, and intersections would then be ranked based on critical rate factor. Locations in various cities may also be compared based on critical rate factor.

A flow chart for the current procedure used to identify high-accident locations in urban areas based on accident rates is the same as for rural highways. The only difference is the values for frequencies, rates, and EPDO accidents used as criteria. Average and critical frequencies for 0.3-mile (0.48-km) spots and 1.0-mile (1.6-km) sections for urban highways were given in Table 4. Also, curves giving the critical frequencies for section lengths up to 20 miles (32 km) are given in APPENDIX C.

Spots and sections qualifying are then tested by the rate-quality control and EPDO methods. Statewide accident rates for urban spots and sections were calculated from 1978 data (Table 8) (11). Critical rates for spots were calculated as before using Equation 3. Curves giving these rates by AADT are given in Figure 7. Critical rates for sections were calculated as a function of section length and AADT. For example, the curves for four-lane, undivided streets are given in Figure 8. The curves for other urban highway sections are given in APPENDIX F.

Average and critical number of EPDO accidents for 0.3-mile (0.48-km) spots and 1.0-mile (1.6-km) sections for urban highways are given in Table 7. These can be used in the EPDO method. Also, curves giving the critical frequencies for section lengths up to 20 miles (32 km) are given in APPENDIX C.

As with rural highways, a matching procedure is used to identify high-accident locations on streets without route numbers and mileposts.

It should be noted that both rural and urban locations are identified on the

Table 8. Accident Rates for Spots and Sections of Urban Highways (1978 Accident Data).

HIGHWAY	AVERAGE STATEWIDE ACCIDENT RATES	
	SPOTS (ACCIDENTS PER MILLION VEHICLES)	SECTIONS (ACCIDENTS PER 100 MILLION VEHICLE MILES)
TWO-LANE	2.25	751
FOUR-LANE DIVIDED (NO ACCESS CONTROL)	1.97	656
FOUR-LANE UNDIVIDED	2.74	911
INTERSTATE	0.68	227
PARKWAY	0.31	101

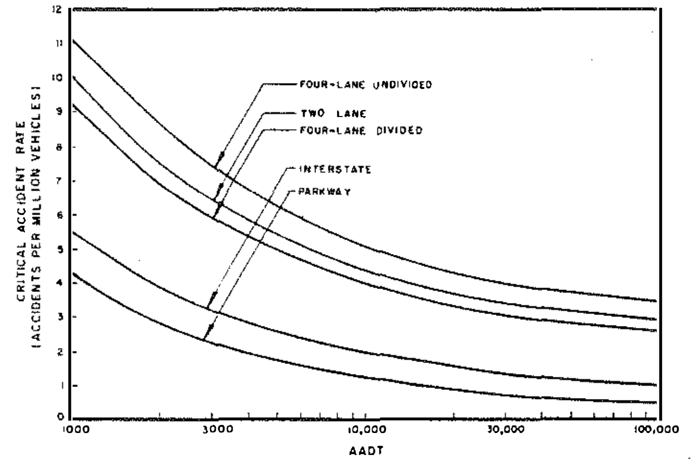


Figure 7. Critical accident rates for 0.3-mile (0.48-km) spots on urban highways (one-year data) (P = 99.5).

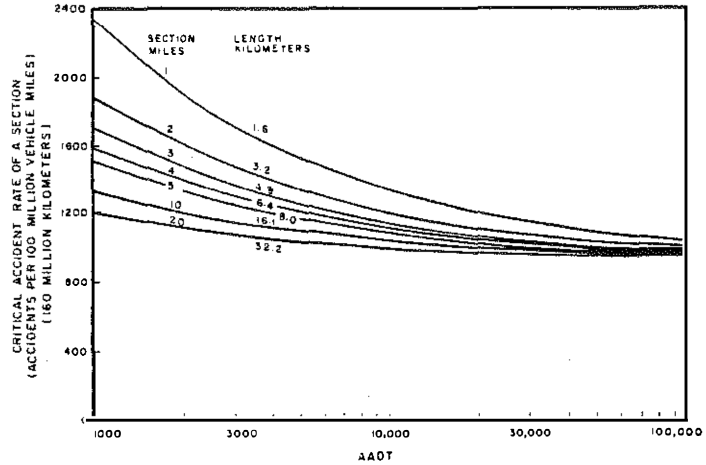


Figure 8. Critical accident rates for urban, four-lane, undivided highway sections (one-year data) (P = 99.5).

basis of total accidents. These procedures do not attempt to identify locations which have had critical frequencies of certain types of accidents. For example, critical nighttime accident rates have been determined. This program may be further expanded to identify locations which have had a critical frequency or rate of a certain type of accident.

Investigating Hazardous Locations

After high-accident locations are identified and ranked, a detailed investigation of the sites ensues. The procedures involve the following (4):

1. preparing collision diagrams,
2. summarizing accident characteristics,
3. conducting field observations, and
4. selecting specific improvements.

Collision Diagrams

Collision diagrams are used to analyze accident patterns. They include schematic drawings of accidents along with such information as (4):

1. location description,
2. general layout of location,
3. time and date of each accident,
4. severity of each accident,
5. pavement condition during each accident (wet, dry, or icy),
6. weather condition during accident,
7. paths of vehicles involved, and
8. traffic control devices present.

A sample diagram is shown in Figure 9. The form was developed by the Division of Traffic.

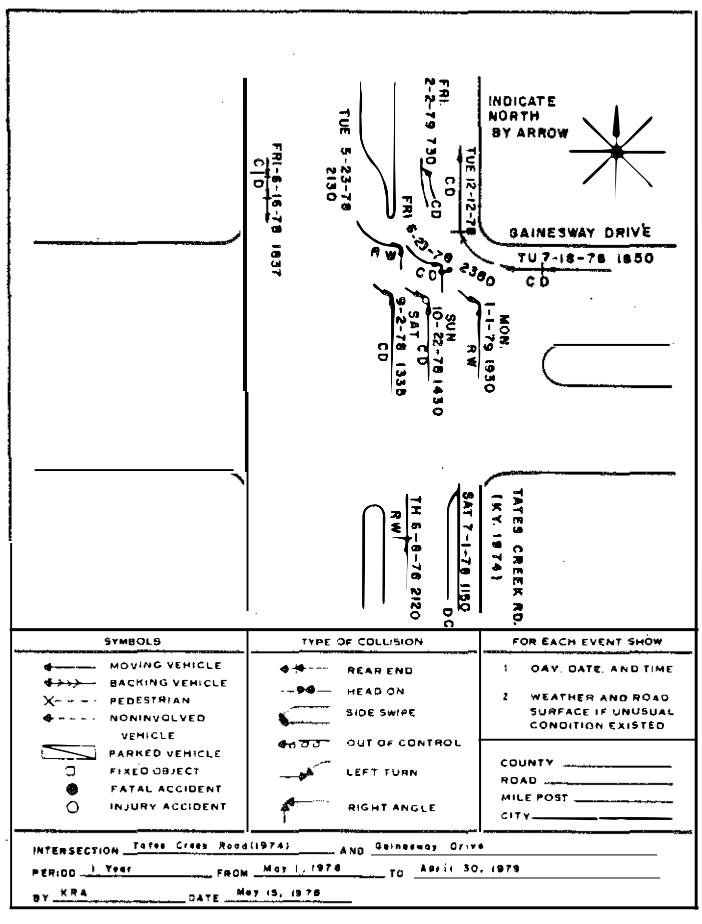


Figure 9. Intersection collision diagram.

The accident analysis is used to determine the type of safety improvement needed. Factors related to the driver, such as the type of driver error, and the vehicle, such as vehicle defects, may be studied in addition to the roadway factors. Road surface conditions, lighting, sight restrictions, and existing traffic control devices may be considered.

Condition Diagrams

A condition diagram is a scalar map showing many of the physical features of the location. Features such as roadway and shoulder widths, view obstructions, grades, traffic control, lighting, curbs, sidewalks, parking, and driveways may be shown. A condition diagram is sometimes used to assist in the selection of safety improvements whenever field inspection is not possible (8). It also can be used as a reference in the office to check dimensions, distances, etc., after the field inspection has been made. Photographs may be used as a permanent record of conditions. An example of a condition diagram is given in Figure 10. No specific form is used for drawing a condition diagram. Entries may describe conditions up to 200 feet (61 m) from major approaches.

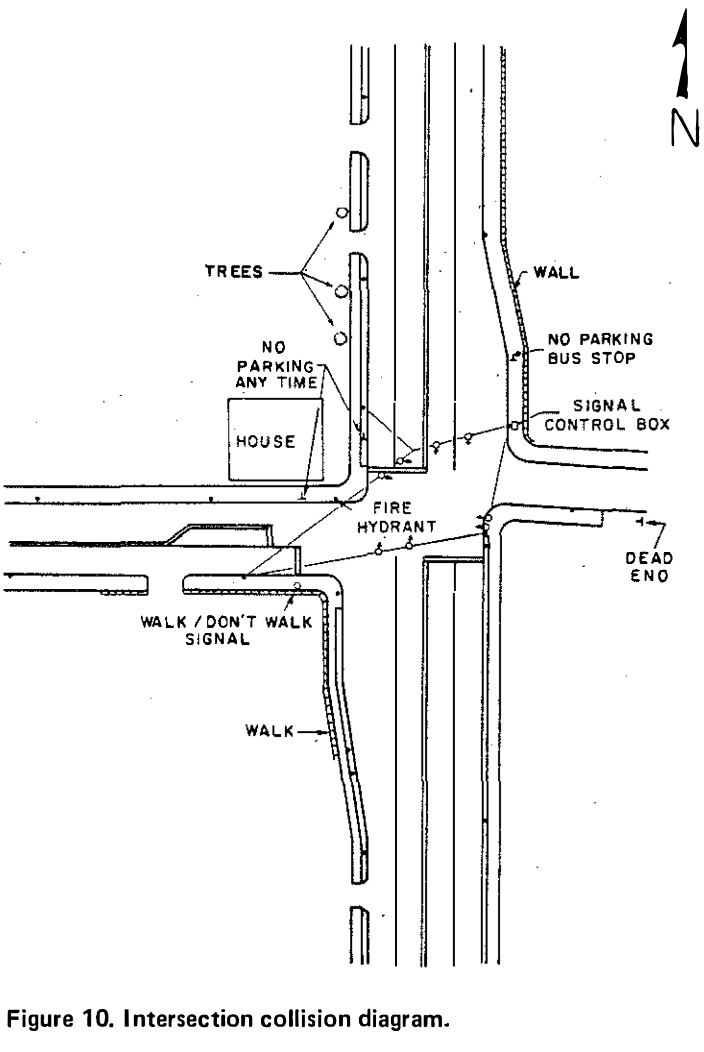


Figure 10. Intersection collision diagram.

Traffic Data Collection

To properly evaluate problems at intersections or other locations, traffic speeds, vehicle delays, volumes, and vehicle types may be helpful in selecting an appropriate safety improvement. Speed studies are particularly helpful in analyzing accidents at intersections and on sharp curves. Data are collected using a radar meter with digital readout. Speeds are recorded separately for cars and trucks on data forms shown in Figure 11. Size of the data set should be at least 100 vehicles, and may be determined more specifically based on statistical tests given by Pignataro (14).

Volume information is routinely collected by the Division of Highway Systems for most state-maintained roads and other selected roads. Such volume data are available on state AADT maps and in tabular form. A computerized, statewide volume file is also available. For more specific volume counts by vehicle classification, a special form is used (Figure 12). For recording vehicle turning movements at intersections, another form is available (Figure 13).

Delay studies are useful in analyzing problems at urban intersections. One method of counting stopped-time delay is to time each vehicle from stopping to clearing the stop bar. However, at high-volume intersections, the procedure normally used involves counting the number of vehicles stopped on each intersection approach at periodic intervals (each 15 or 20 seconds). By multiplying the number of stopped vehicles by the time interval used, the approximate stopped-time delay can be found. The form shown in Figure 14 is used to collect the data.

Conflict Analysis

Traffic conflicts may be observed at a location to provide valuable information concerning driver confusion or error. A

MOTOR VEHICLE SPEED FIELD SHEET (RADAR)

COUNTY	ROUTE NO.	ZONE MPH	DATE
TIME TO	DAY	WEATHER	N.S.E.W. BOUND

LOCATION

PAVEMENT CONDITIONS

REMARKS

SPEED	AUTOMOBILES				SPEED	TRUCKS	BUSSES	CUMULATIVE	
		TOT.	CUMULATIVE TOTAL	PERCENT				TOTAL	PERCENT
100					100				
95					95				
90					90				
85					85				
80					80				
78					78				
76					76				
74					74				
72					72				
70					70				
68					68				
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26					26				
24					24				
22					22				
20					20				
18					18				
16					16				
14					14				
12					12				
10					10				

OPERATOR ______________________

Figure 11. Motor vehicle speed field sheet (radar).

OBSERVER ____________

DATE ____________

WEATHER ____________

VEHICLE CLASSIFICATIONS
LANE DISTRIBUTIONS

LOCATION ____________

DIRECTION ____________

TIME INTERVAL ____________

LANE	AUTOS AND PICKUPS (FROM COUNTER)	AUTOS, PICKUPS OR SU-2A-4T WITH TRAILER	BUSES	SU-2A-4T	SU-2A-6T	SU-3A	SU-4A	C-3A	C-4A	C-5A	C-6A	OTHER	TOTAL
SHOULDER													
MEDIAN													
TOTAL													

COMMENTS:

Figure 12. Vehicle classification volume count data sheet.

VEHICULAR VOLUME DISTRIBUTION
SUMMARY

Date________________ Day________________ Location________________________

Weather________________________________ Computer________________________

Remarks____

Per.	—— On ———— St.				—— On ———— St.				—— On ———— St.				—— On ———— St.				TOTALS		
End.	Lt	St	Rt	Tot	Lt	St	Rt	Tot.	Lt	St	Rt	Tot	Lt	St	Rt	Tot	Main.	Side	Both
7:30																			
8:00																			
8:30																			
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6:00																			
6:30																			
7:00																			
TOTALS																			

Figure 13. Intersection vehicular volume distribution summary.

DATE ____________
TIME ____________
APPROACH ______________________
REMARKS ____

VOLUME STOPPED ____________
NON STOPPED ________
TOTAL ____________ = V

ACTUAL TIME	NUMBER OF STOPPED VEHICLES AT–			
(MINUTE BEGINNING)	+00SEC	+15SEC	+30SEC	+45 SEC
:				
:				
:				
:				
:				
:				
:				
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:				

TOTALS FOR PERIOD (15 SECOND INTERVAL) = ________ = T
AVERAGE DELAY PER VEHICLE = (T x 15) / V = ________ SECONDS

Figure 14. Intersection delay data collection form.

conflict occurs when a driver commits a violation or makes an evasive action such as braking or weaving to avoid colliding with another vehicle or pedestrian. Types and frequencies of conflicts are measures of accident potential and operational problems. Many highway agencies are now using conflict data to complement accident data (15). Conflict counts enable a quick evaluation of changes in road design, signing, signalization, and other elements. The first formalized procedure for identifying and recording traffic conflicts at intersections was developed by Perkins and Harris of General Motors Corporation in 1967 (16). The use of conflict analysis techniques has been limited primarily to intersections. However, procedures for analyzing other types of locations are under development (15).

Major types of conflicts at intersections include rear-end, left-turn, cross-traffic, red-light violation, and weave conflicts. Erratic maneuvers have also been used along with conflicts. An erratic maneuver is any sudden, unexpected movement by a vehicle that could result in an accident. An erratic maneuver differs from a conflict in that it usually involves only one vehicle commiting an unsafe movement independent of any other vehicle. Whereas traffic conflict counts usually indicate the potential for accidents between two or more vehicles, erratic maneuver counts may provide information about the potential for single-vehicle accidents. A near-miss accident occurs when a collision between two or more vehicles is avoided due to a last-second evasive movement or stop. A near-miss accident is a very severe type of conflict or erratic maneuver; relatively few near-miss accidents may be observed at any location when compared to the number of conflicts or erratic maneuvers (15).

A procedure was developed for the systematic collection of traffic conflict data at intersections. The procedure is based on the General Motors Corporation procedure, but includes modifications in conflict types and data collection times (15, 16). A complete description of Kentucky's conflict procedure along with data forms and conflict definitions is given in Appendix G.

A current study involves relating accidents and conflicts at intersections. A revised intersection conflict data sheet was developed for that study and is also included in APPENDIX G (Figure G9).

The concept of a conflict diagram also has been introduced for use in a similar way as an accident diagram (15). Whereas an accident diagram shows only reported accidents (perhaps less than 50 percent of all accidents), a conflict diagram provides valuable information of near-accidents or potential accidents. An example of a conflict diagram is shown in Figure 15. The number of occurrences of each conflict type is given on each sketch. Moderate or severe conflicts are given in parenthesis.

Field Inspections

Locations found to be hazardous based on accident experience are inspected by a multidisciplinary team consisting of traffic engineers, maintenance engineers, police, and representatives of the appropriate highway district. Physical attributes of the location are studied along with other information such as collision diagrams, volume data, speed data, and delay information. Traffic flow is observed to detect any noticeable driver error or confusion. Recommendations for safety improvements are made by the investigative team.

Selecting Improvements

The selection of improvements must be made with the entire highway system in mind. For example, if changes in signal timing at an intersection are recommended, the effect of this change on adjacent signals must be known in terms of signal coordination and traffic flow. Care should be taken, for example, when reconstructing a section of road so no abrupt geometric changes will be introduced.

Based on eight specific types of accidents, a listing of suggested corrections at hazardous locations has been prepared (14). This listing is a guide for traffic engineers to select improvements for the reduction of specific accident types. This listing is given in APPENDIX H.

Several important points should be remembered when selecting highway improvements (4):

1. Identify all practical improvements -- everything from the do-nothing alternative to the ultimate improvement such as major reconstruction. Several alternatives can be considered in the economic analysis which will point to the best solution.
2. Identify all realistic combinations of improvements.
3. Identify the expected effect of all improvement combinations on all accidents (types and severities). This input is used for budgeting the safety improvements.

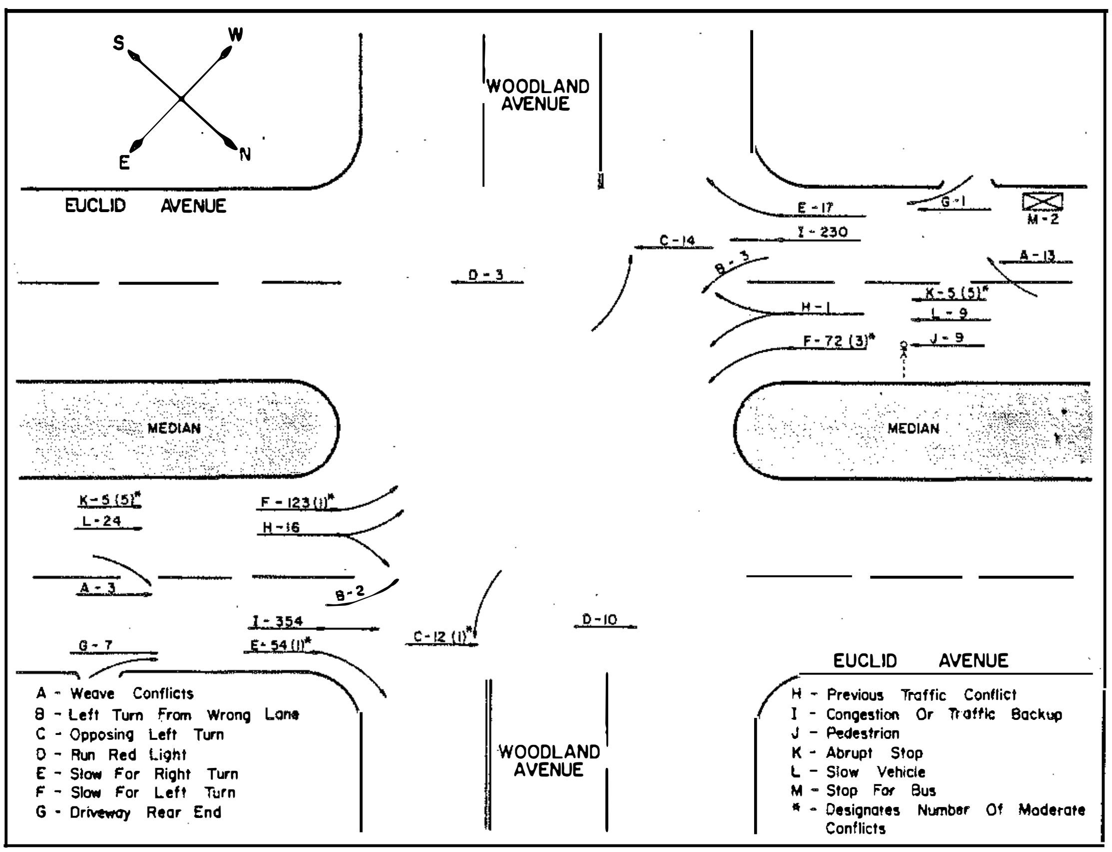

Figure 15. Conflict diagram at Euclid Avenue and Woodland Avenue intersection (Lexington).

Budgeting Safety Improvements

To budget safety improvements to yield the greatest benefit, an economic evaluation requires the input of construction and maintenance costs and benefits to be derived from accident reduction and other sources. The expected benefits and costs may then be compared by some method such as benefit-cost analysis, and project ranking and selection may be ordered by dynamic programming.

Estimates are to be made of benefits and costs for each improvement proposed. An economic analysis, of course, is only as reliable as the estimates of benefits and costs. Based on 447 improvements in Kentucky, average service lives, annual maintenance costs, and percentage reduction in accidents were determined and used as cited in Table 9 (17). Those improvements included 12 different types at intersections, 7 types for curves, and 19 general improvements. Annual maintenance costs varied from zero for renewable improvements such as pavement markings to $500 for highway lighting. Service lives of improvements ranged from 2 years for markings to 20 years for highway realignment projects. Accident reduction varied widely by improvement type and was highest (48 percent) for the installation of regulatory signs.

Table 9. Summary of Improvement Cost and Benefits.

	TYPE OF IMPROVEMENT	NUMBER OF PROJECTS	TOTAL ACCIDENT REDUCTION (PERCENT)	SERVICE LIFE (YEARS)	ANNUAL MAINTENANCE COST ($)
General	Signs and Markings	9	36	3	25
	Warning Signs	23	35	5	25
	Regulatory Signs	16	22	5	25
	Guidance Signs	10	14	5	25
	Sign Combinations	16	20	5	25
	Markings	8	16	2	0
	Sight Distance Imp.	9	28	2	50
	Post Delineators	3	25	5	20
	Comb. Delineators. Markings, Signs, Maintenance	11	22	5	25
	Shoulder Improvements	7	23	10	100
	Comb. Resurface, Patching, Drainage, Deslick, Culvert	22	16	10	100
	Rumble Strips	8	29	5	0
	Remove Median Crossovers	2	29	20	0
	Lighting	1	-58	10	500
	Lighting & Rumble Strips	1	17	7	300
	Rumble Strips & Beacon	2	32	7	50
	Side Road Sign Only	31	19	5	25
	Prepare for Sudden Stop Sign Only	19	25	5	25
	Side Road Sign & Warning Sign	15	27	5	25
Curves	Signing	34	30	5	25
	Post Delineators	4	32	5	25
	Signs & Delineators	16	28	5	25
	Signs & Maintenance	6	47	3	25
	Comb. Delineators, Markings, Signs, Maintenance	16	24	5	25
	Resurfacing, Patch, Drainage, Deslick, Super, Culvert, Guardrail	22	33	10	100
	Re-alignment (Relocate)	3	32	20	100
Intersections	Signs & Markings	21	24	3	25
	Warning Signs	11	27	5	25
	Regulatory Signs	5	48	5	25
	Regulatory & Warning Signs	20	16	5	25
	Markings	17	16	2	0
	Marking, Maintenance, & Signing	9	35	5	25
	Channelization - Storage Lane	13	15	10	100
	Channelization & Signs	2	37	7	75
	Install Beacons	13	2	10	100
	Upgrade Beacons	10	5	10	100
	Install Signals	10	23	10	300
	Upgrade Signals	2	18	10	250
	Total Improvements	447	24		

Dynamic programming (17) is an optimization technique that transforms a multistage decision problem into a series of one-stage decision problems. There are three main reasons why dynamic programming is used. First, it is designed to provide the best plan over a period of time. Second, it is possible to obtain the best combination of projects. Third, it yields an optimal investment plan when the usual benefit-cost, present worth, or maximum rate of return approaches are not practical. When the amount of money required for a single project is a large portion of the budget, the best set of projects does not necessarily consist of those which would be chosen by the conventional means of priority selection.

Detailed knowledge of the mechanics of dynamic programming is not required to implement a program. The input consists only of the costs and benefits anticipated for each project along with the time required for completion. Dynamic programming, by taking every possible combination of projects into account, avoids the possibility of missing much needed projects. The program currently used was developed in 1974 (17). It is based partly on Alabama's CORRECT system (18, 19). Dynamic programming has also been used in the selection of projects for resurfacing (20).

To calculate benefits, an interest rate must be selected -- 10 percent has been commonly used. A traffic growth factor must be determined or assumed (about 5 percent is normally used). Costs of fatalities, injuries, and property damage must be inputed into the model. National Safety Council costs are used. Accident costs for 1979 are given below:

1. fatality = $160,000
2. injury = $6,200
3. property-damage = $870

The number of accidents in a chosen period of time at each location is multiplied by the expected percentage reduction of accidents for each improvement alternative. The annual benefits are then multiplied by an exponential growth, present-worth factor to obtain the present-worth benefits for the entire service life of the improvement.

The costs are the sum of the improvement cost and the maintenance cost for each project. A present-worth factor is used to adjust the maintenance costs at a future date to the present.

It is very difficult to estimate benefits and costs. Even with a large sample of before-and-after data for similar locations and improvements, accident reduction estimates may be inaccurate. This is attributable in part to differences in characteristics of seemingly similar highway locations. Spuriousness in accident occurrences contributes to the uncertainty in predicting future accidents. Predictions of reductions should be based on large data samples and be guided by engineering judgments. If benefit and cost inputs are carelessly or incorrectly estimated, results of dynamic programming will be equally in error.

One type of output from the dynamic programming model is presented in Table 10. This listing is by location number (1 to 61) and includes coded location information (county, route, and milepost), alternative number (1 to 7), project cost, dollar return (accident benefit), and benefit-cost ratio. After dynamic programming is constrained within a specified budget, projects are selected as shown in Table 11. This printout includes the projects selected and cites projects not selected due to insufficient funds (coded 0). The costs and returns are also cited there for each project along with totals (bottom of page) and accumulated returns. A copy of the computer program, a listing of variables, the input coding instructions, and other information necessary to implement the program have been provided in a previous report (17). The source deck for the dynamic programming program, however, is provided in APPENDIX I.

Table 10. Summary Output from Dynamic Programming.

LOCATION NO.	LOCATION NAME	ALTERNATIVE NO.	COST	RETURN	B/C RATIO
1	63-25-10.9	1	1500.	7620.	5.08
2	30-66-15.1	1	4250.	158707.	37.34
3	30-60-15.2	1	2000.	11385.	5.69
4	54-41A-12.0	1	500.	9792.	19.58
5	73-45-6.5	1	500.	973.	1.95
6	73-45-7.2	1	500.	0.	0.0
6	73-45-7.2	2	500.	0.	0.0
6	73-45-7.2	3	750.	6726.	8.97
7	48-421-14.4	1	500.	0.	0.0
7	48-421-14.4	2	500.	588.	1.18
7	48-421-14.4	3	750.	0.	0.0
8	20-51-1.1	1	750.	2987.	3.98
9	102-25-9.2	1	1000.	3365.	3.37
10	102-25-54	1	500.	226.	0.45
11	30-60-15.2	1	500.	16145.	32.29
11	30-60-15.2	2	4750.	3524.	0.74
11	30-60-15.2	3	5000.	31866.	6.37
12	72-641-8.5	1	750.	40588.	54.12
13	30-60-4.1	1	1250.	814.	0.65
14	39-171-65.7	1	4500.	26029.	5.78
15	79-641-18.9	1	750.	3548.	4.73
16	54-41A-12.4	1	500.	14598.	29.20
16	54-41A-12.4	2	500.	3442.	6.88
16	54-41A-12.4	3	750.	18048.	24.05
17	24-68-9.1	1	500.	814.	1.63
17	24-68-9.1	2	500.	916.	1.83
17	24-68-9.1	3	1000.	1729.	1.73
18	114-31W-16.2	1	500.	2649.	5.30
18	114-31W-16.2	2	500.	1422.	2.84
18	114-31W-16.2	3	750.	4071.	5.43
19	63-25-10.0	1	500.	966.	1.93
19	63-25-10.0	2	500.	1272.	2.54
19	63-25-10.0	3	750.	2236.	2.98
20	100-6-5.2	1	500.	373.	0.75
21	37-127-8.7	1	750.	2348.	3.13
22	47-31W-26.0	1	2250.	24654.	10.96
23	30-54-12.6	1	750.	4290.	5.72
24	114-31W-16.1	1	1750.	256.	0.15
25	41-22-11.3	1	500.	5765.	11.53
25	41-22-11.3	2	500.	5765.	11.53
25	41-22-11.3	3	500.	39.	0.08
25	41-22-11.3	4	1000.	11530.	11.53
25	41-22-11.3	5	750.	5855.	7.81
25	41-22-11.3	6	750.	5855.	7.81
25	41-22-11.3	7	1250.	11620.	9.30
26	73-62-17.6	1	500.	424.	0.85
26	73-62-17.6	2	500.	0.	0.0
27	73-45-6.5	1	750.	824.	1.10
28	73-62-16.9	1	2000.	7039.	3.52
28	73-62-16.9	2	1250.	5246.	4.20
28	73-62-16.9	3	3000.	12286.	4.10
29	63-25-10.8	1	750.	746.	0.99
30	54-41A-12.2	1	500.	4528.	9.06
30	54-41A-12.2	2	500.	3985.	7.97
30	54-41A-12.2	3	750.	8513.	11.35
31	72-641-8.5	1	500.	10565.	21.13
31	72-641-8.5	2	1500.	13357.	8.90
31	72-641-8.5	3	2000.	56100.	28.05
32	56-165ATP-130.1	1	1500.	11711.	7.81
33	63-25-10.4	1	750.	746.	0.99
33	63-25-10.4	2	1250.	0.	0.0
34	61-175-155.6	1	4000.	152094.	38.02
35	51-41-20.0	1	2000.	1078.	0.64
36	1051-41-20.6	1	500.	4699.	9.40
37	82-31W-1.1	1	500.	17166.	34.34
38	64-65-11.5	1	1000.	34480.	34.49
39	120-60-12.6	1	500.	9006.	18.02
40	82-60-12.3	1	500.	11078.	22.16
41	10-60-8.3	1	500.	593.	1.19
42	79-641-13.0	1	500.	1064.	2.13
43	51-60-20.3	1	750.	86411.	115.21
44	70-60-11.	1	750.	412.	0.55
45	82-US60-12.7	1	750.	9097.	12.13
46	82-US60-12.7	1	1750.	4488.	2.56
47	82-31W-1.0	1	500.	922.	1.84
48	30-60-15.6	1	4250.	2792.	0.66
49	10-60-9.2	1	500.	2664.	5.33
49	10-60-9.2	2	750.	3196.	4.26
49	10-60-9.2	3	750.	5860.	7.81
50	79-641-12.5	1	500.	8710.	17.42
50	79-641-12.5	2	750.	5784.	7.71
50	79-641-12.5	3	1000.	17152.	17.15
51	79-641-12.5	1	1000.	26532.	26.53
52	70-US60-11.3	1	500.	626.	1.25
52	70-US60-11.3	2	750.	1649.	2.20
52	70-US60-11.3	3	1000.	366.	0.37
52	70-US60-11.3	4	2000.	1465.	0.73
52	70-US60-11.3	5	1750.	8021.	4.58
52	70-US60-11.3	6	4000.	13348.	3.34
52	70-US60-11.3	7	4250.	14447.	3.40
53	47-31W-23.3	1	2000.	4894.	2.45
54	63-25-10.4	1	500.	4735.	9.47
54	63-25-10.4	2	500.	5380.	10.76
54	63-25-10.4	3	1000.	10115.	10.11
54	63-25-10.4	4	1500.	1889.	1.26
54	63-25-10.4	5	1750.	10200.	5.83
54	63-25-10.4	6	2000.	11334.	5.67
54	63-25-10.4	7	2250.	19645.	8.73
55	102-75-11.9	1	500.	3934.	7.87
56	82-31W-2.2	1	2500.	6780.	2.71
57	51-41-20.0	1	500.	10791.	21.58
58	82-31W-1.2	1	500.	1921.	3.84
59	30-60-16.4	1	500.	1731.	3.46
59	30-60-16.4	2	500.	2338.	6.68
60	22-60-26.2	1	750.	221.	0.29
61	63-25-10.0	1	500.	287.	0.57
61	63-25-10.0	2	500.	326.	0.65
61	63-25-10.0	3	1000.	613.	0.61
61	63-25-10.0	4	1500.	114.	0.08
61	63-25-10.0	5	1750.	618.	0.35
61	63-25-10.0	6	2000.	687.	0.34
61	63-25-10.0	7	2250.	1191.	0.53

Table 11. Alternatives Selected with Dynamic Programming for a Given Budget.

ALTERNATIVES SELECTED
FOR $50,000 BUDGET

BUDGET	LOCATION	LOCATION NAME	ALT-NUM	COST	RETURN	ACCUM RETURN
50000.00						
	61	63-25-10.0	0	0.	0.	868692.
	60	22-60-26.2	0	0.	0.	868692.
	59	30-60-16.4	2	500.	3338.	868692.
	58	82-31W-1.2	1	500.	1921.	865354.
	57	51-41-20.0	1	500.	10792.	863433.
	56	82-31W-2.2	0	0.	0.	852640.
	55	102-25-11.9	1	500.	3934.	852640.
	54	63-25-10.4	7	2250.	19645.	848707.
	53	47-31W-23.3	0	0.	0.	829062.
	52	70-US60-11.3	5	1750.	8021.	829062.
	51	79-641-12.5	1	1000.	26532.	821040.
	50	79-641-12.5	3	1000.	17152.	794508.
	49	10-60-9.2	3	750.	5860.	777356.
	48	30-60-15.0	0	0.	0.	771496.
	47	82-31W-1.0	0	0.	0.	771496.
	46	82-US60-12.7	0	0.	0.	771496.
	45	82-US60-12.7	1	750.	9097.	771496.
	44	70-60-11.4	0	0.	0.	762399.
	43	51-60-20.3	1	750.	86411.	762399.
	42	79-641-13.0	0	0.	0.	675988.
	41	10-60-8.3	0	0.	0.	675988.
	40	82-60-12.3	1	500.	11078.	675988.
	39	120-60-12.6	1	500.	9008.	664910.
	38	84-68-13.5	1	1000.	34486.	655902.
	37	82-31W-1.1	1	500.	17168.	621416.
	36	051-41-20.0	1	500.	4699.	604248.
	35	51-41-20.0	0	0.	0.	599549.
	34	41-175-155.6	1	4000.	152094.	599549.
	33	63-25-10.9	0	0.	0.	447455.
	32	56-165KTP-130.1	1	1500.	11711.	447455.
	31	72-641-8.5	3	2000.	56100.	435743.
	30	54-41A-12.2	3	750.	8513.	379644.
	29	63-25-10.8	0	0.	0.	371131.
	28	73-62-16.9	3	3000.	12286.	371131.
	27	73-45-6.5	0	0.	0.	358846.
	26	73-62-17.8	0	0.	0.	358846.
	25	41-22-11.3	4	1000.	11530.	358846.
	24	114-31W-16.1	0	0.	0.	347316.
	23	30-54-12.6	1	750.	4290.	347316.
	22	47-31W-26.0	1	2250.	24654.	343026.
	21	37-127-8.7	0	0.	0.	318372.
	20	106-6-3.2	0	0.	0.	318372.
	19	63-25-16.0	0	0.	0.	318372.
	18	114-31W-16.2	3	750.	4071.	318372.
	17	24-68-9.1	0	0.	0.	314301.
	16	54-41A-12.4	3	750.	18040.	314301.
	15	79-641-18.9	1	750.	3548.	296261.
	14	39-171-63.7	1	4500.	26029.	292713.
	13	30-60-4.1	0	0.	0.	266684.
	12	72-641-8.5	1	750.	40588.	266684.
	11	30-60-15.2	3	5000.	31866.	226095.
	10	102-25-54	0	0.	0.	194229.
	9	102-25-9.2	0	0.	0.	194229.
	8	26-51-1.1	0	0.	0.	194229.
	7	48-421-14.4	0	0.	0.	194229.
	6	73-45-7.2	3	750.	6726.	194229.
	5	73-45-6.5	0	0.	0.	187504.
	4	54-41A-12.0	1	500.	9792.	187504.
	3	30-60-15.2	1	2000.	11385.	177712.
	2	30-60-15.1	1	4250.	158707.	166327.
	1	63-25-10.9	1	1500.	7620.	7620.
****************	TOTALS	******************************		50000.	868692.	868692.

Evaluation of Improvements

After improvements are completed, an analysis may be made to evaluate the effectiveness of the improvements. This analysis involves a comparison of before and after data to determine what changes have occurred. Primarily, the evaluation involves an accident analysis; however, other evaluation criteria may also be applied.

Accident Studies

Comparison of before and after accidents shows the effectiveness of the improvements in reducing accidents. Also, the reductions may be used to improve predictions of the benefits to be derived from specific types of improvements. The basic data needed is a summary of accidents for at least a 1-year period before and after the improvement was completed. Two years of before data, of course, provide more reliable results than one year of data (9). A summary of accidents by location may be obtained using the Kentucky Accident Reporting System (KARS). However, it may be necessary to perform manual searches to ensure that all accident reports are being counted. Either a copy of each accident report may be obtained and used, or the accident information may be entered onto an accident report form developed by the Division of Traffic (Figure 16).

KENTUCKY DEPARTMENT OF TRANSPORTATION
DIVISION OF TRAFFIC
ACCIDENT REPORT FORM

TD 72-1
Rev. 11-77

Date ______________

1. DATE OF ACCIDENT	DAY OF WEEK	TIME OF DAY OF ACCIDENT

2. LOCATION OF ACCIDENT

Route/Street ______________ Mile Post ______________

At Intersection with ______________ Route/Street

3. VEHICLE TYPE AND DIRECTION OF TRAVEL

Vehicle 1 ______________ headed N ☐ E ☐ S ☐ W ☐ on ______________

Vehicle 2 ______________ headed N ☐ E ☐ S ☐ W ☐ on ______________

4. TYPE OF ACCIDENT

_______ Head on
_______ Sideswipe
_______ Rear End
_______ Right Angle
_______ Left Turn
_______ Fixed Object
_______ Pedestrian
_______ Other _______

5. VISIBILITY

_______ Daylight
_______ Night
_______ Dusk
_______ Fog
_______ Rain

6. ROAD SURFACE

_______ Dry
_______ Wet
_______ Ice
_______ Snow
_______ Other _______

7. CAUSE OF ACCIDENT

_______ Followed Too Closely
_______ Inattentive
_______ Excessive Speed
_______ Ran Red Signal
_______ Failed to Yield
_______ Drove While Intoxicated
_______ Ran Stop Sign
_______ Passed Improperly
_______ Turned Improperly
_______ U Turn
_______ Mechanical Failure
_______ Failed to Signal
_______ Jay Walked
_______ Other _______

REMARKS CONCERNING CAUSE OF ACCIDENT

CIRCLE ONE

PDO	INJ	FATAL

8. COMMENTS, DIAGRAM, ETC. NEEDED TO DESCRIBE THE ACCIDENT

Data Collected by ______________ Report Prepared by ______________
AGENCY

Figure 16. Accident report form, Division of Traffic, Kentucky Department of Transportation.

A "Location Improvement Worksheet" has been developed (Figure 17). Before and after data are summarized. Traffic volumes are entered so rates may be calculated and compared. The percentage reduction in accidents is also determined. Finally, an economic analysis is performed in terms of a benefit-cost ratio as shown in Figure 17. It is generally recognized that a ratio of one or greater means that the improvement was a worthy one.

A statistical evaluation may be made by application of the Chi-Square and Poisson distributions. Curves for determining the statistical significance of accident reduction are given in Figure 18 (21). The information needed is the number of accidents before improvement and the reduction after the improvement. The actual reduction may then be compared to the reduction required (Figure 18) to be significant. The curves are for a 95-percent level of confidence that the reduction was significant. This means

LOCATION CODE

UPDATED BY

LOCATION IMPROVEMENT WORKSHEET

COUNTY________ ROUTE________

MILEPOST________ INTERSECTING________

ACCIDENT EXPERIENCE:

	BEFORE			AFTER		
FROM			TOTAL			TOTAL
TO						
ADT						
EXPOSURE						
TOTAL ACC						
FATAL ACC						
FATALITIES						
INJURY ACC						
INJURIES						
PDO ACC						
RATE						

% REDUCTION 100(BT - AT)/BT = ________

COMPLETION ________ ________
DATE COST

IMPROVEMENT CODE________

(BT - AT) x 2,800 = EUAB ________

CRF (I) + K = EUAC ________

EUAB/EUAC = B/C = ________

BT = Number of before accidents
AT = Number of after accidents
CRF= Capital recovery factor
I = Initial cost

K = Annual maintenance cost
EUAB= Equivalent uniform annual benefit
EUAC= Equivalent uniform annual cost

Figure 17. Location improvement worksheet.

there is only a five-percent probability the reduction occurred merely by chance. Depending on the reliability of the accident data, one of the two curves in Figure 18 may be selected for use. The Poisson distribution may be used when two or more years of accident data are available for the before period (22).

More detailed accident analyses may be performed. A common analysis is to compare the severity of the before and after accidents. The frequency or percentage of injury or fatal accidents may be compared. The severity index may also be used (9). A comparison between specific types of accidents may also be performed (a safety improvement could affect various types of accidents differently). Other analyses could include comparisons of various pavement surface conditions, light conditions, and other contributing factors.

Other Evaluations

In addition to detailed analyses and calculations of benefit-cost ratios, other criteria may be applied to the evaluation of safety improvements. Other criteria are given in Table 12. Accidents and benefit-cost ratios have been the primary criteria. An analysis of traffic speeds could include comparison of the average speed, 85th percentile speed, and 10-mph (4.5-m/s) pace. Conflicts and erratic maneuvers may be observed to find those conflicts and maneuvers that may be affected by the improvements. An analysis of delays and volumes may be useful after installation of a traffic signal. Brake applications have been used to evaluate improvements such as delineation of stop approaches. Encroachments and lateral

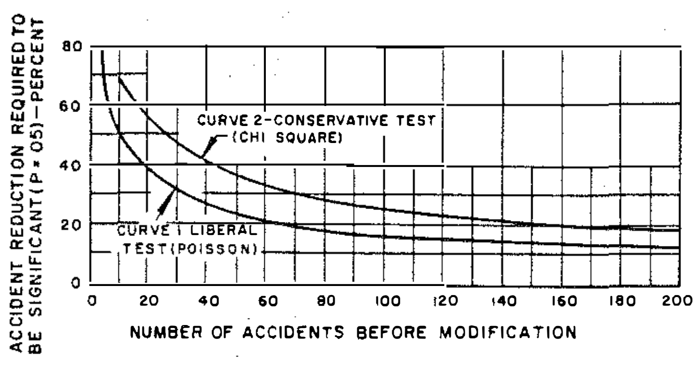

Figure 18. Curves for determining the statistical significance of accident reduction.

Table 12. Evaluation Criteria for Safety Improvements.

PRIMARY	ACCIDENTS BENIFIT-COST RATIO
OTHER CRITERIA	SPEEDS TRAFFIC CONFLICTS ERRATIC MANEUVERS DELAYS VOLUMES CAPACITY BRAKE APPLICATIONS ENCROACHMENTS LATERAL PLACEMENT ENVIRONMENTAL (NOISE LEVELS AND AIR QUALITY)

placement have been used to evaluate improvements at curves. Also, evaluations of traffic signal systems have included an analysis of noise levels and air quality in addition to delays, volumes, capacity, and accidents.

Program Evaluation

In addition to an evaluation of individual safety improvements, an evaluation of the entire program may be useful. A previous report cited an evaluation of the high-accident spot-improvement program in Kentucky (9). Such an evaluation would determine the overall effectiveness of the program. A determination of the type of improvements made and a comparison of the benefits derived from the various safety improvements may be highly desirable.

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Appendix A.

REPORTING FEATURES OF THE KENTUCKY
ACCIDENT REPORTING SYSTEM

KARS Reporting Features

ON-LINE INQUIRIES -- Response given on CRT's

MASTER CASE NUMBER -- Allows access to any specified accident report. Normally used in conjunction with the Location Inquiry Report (R-1346) to determine if additional in-depth investigation is necessary.

LOCATION INQUIRY -- Provides inquiry by roadway section or by intersection. This report is identical to the first 80 print positions of Report R-1346.

BATCH REPORTS -- Response provided by printout.

R-1340* -- DETAIL LISTING OF ALL ACCIDENTS BY LOCATION -- Provides a detail listing of all accidents by route number or street name.

R-1341* -- DETAIL LISTING OF ALL ACCIDENTS WITH CONTRIBUTING ENVIRONMENTAL FACTORS -- This report identifies accident locations where the roadway environment was a causitive or contributing factor to the accident.

R-1342 and R-1343 -- ACCIDENT BUILDUP LISTING -- These reports are used to aid in identifying high-accident locations.

R-1344 -- AID SYSTEM ACCIDENT SUMMARY -- This report summarizes accidents by AID Systems. It is used to satisfy annual federal reporting requirements.

R-1345* -- AGENCY ACCIDENT SUMMARY -- This report is used to determine accident activity by specific police agency.

R-1346 -- SELECTED LOCATION DETAIL LISTING -- This report identifies certain characteristics of all accidents within a specified time period at a particular location or roadway section (route, street, or intersection) to aid in surveillance of high-accident locations.

R-1347 -- DETAIL ACCIDENTS BY AGENCY -- This report is used to determine accident activity by agency. It is sent to local police departments for use in Selective Enforcement Programs and is used by the Office of Highway Safety in determining federal grant approvals.

*Reports R-1340, R-1341, and R-1345 may be run by any of the the following eleven political jurisdictions or subsets of these jurisdictions. The R-1341 may be run by "all" highway districts or by an individual "highway" district. If it is run by "all", the entire state would be provided, collated by highway district. If it is run by a particular district, only the counties associated with that district would be provided.

1. County
2. Highway District
3. State Police Post
4. Area Development Districts
5. Emergency Medical Service (E.M.S.) Districts
6. Disaster Areas
7. Judicial Districts
8. State Senatorial Districts
9. State Legislative Districts
10. U. S. Congressional Districts
11. Sheriff's Districts

Appendix B.

LIST OF VARIABLES FOR THE "RECORDS
ANALYSIS FOR PROBLEM IDENTIFICATION AND DEFINITION (RAPID)"
SOFTWARE PACKAGE

Number	Variable
1	County
2	Highway District Office
3	State Police Post
4	Area Development District
5	EMS Region
6	Disaster Emergency Service
7	Incorporated City Name
8	Accident Year
9	Accident Month-Day
10	Accident Month
11	Accident Day of Week
12	Accident Time of Day
13	Occurrences by Number of Units Involved
14	Occurrences by Number Killed
15	Occurrences by Number Injured
16	Severity of Accident
17	Severity of Injury
18	Description of Accident
19	Type of Accident - 1st Event
20	Location of Accident - 1st Event
21	Directional Analysis
22	Hit and Run Accident
23	AID System
24	Rural or Urban
25	Federal-Aid Classification
26	Toll or Free
27	State, Local, Lot, etc.
28	Access Control
29	Lane Use-Locality
30	Highway Type
31	Number of Traffic Lanes
32	Roadway Surface Type
33	Character of Roadway
34	Weather Conditions
35	Roadway Conditions
36	Light Conditions
37	Traffic Control #1
38	Traffic Control #2
39	Speed Limit Major Trafficway
40	Photos Taken at Scene
41	Chemical Test Administered
42	Enforcement Action Taken
43	First Aid Given at Scene
44	Victim #1 Removed By
45	Victim #2 Removed By
46	Lapsed Time Occurred to Notified
47	Lapsed Time Notified to Arrival
48	Lapsed Time Occurred to Scene Cleared
49	Pedestrians Action
50	Human Contributing Factors Involved
51	Unsafe Speed a Factor
52	Fail to Yield Right of Way a Factor
53	Following Too Close a Factor
54	Improper Passing a Factor
55	Disregard Traffic Controls a Factor

56	Improper Turn a Factor
57	Alcohol a Factor
58	Drugs a Factor
59	Sickness a Factor
60	Falling Asleep a Factor
61	Loss of Consciousness a Factor
62	Driver Inattention a Factor
63	Distractions a Factor
64	Physical Disability a Factor
65	Other Human Factors Involved
66	Vehicular Contributing Factors Involved
67	Defective Brakes a Factor
68	Defective Headlights a Factor
69	Other Lighting Defects a Factor
70	Defective Steering a Factor
71	Tire Failure-Inadequate Tires a Factor
72	Defective Tow Hitch a Factor
73	Overload-Improper Load a Factor
74	Oversized Load a Factor
75	Other Vehicular Factors Involved
76	Environmental Factors Involved
77	Animal Actions a Factor
78	Glare a Factor
79	Obstructed or Limited View a Factor
80	Debris in Roadway a Factor
81	Improper-Nonworking Traffic Control a Factor
82	Defective Shoulders a Factor
83	Holes, Deep Ruts, Bumps a Factor
84	Road Construction-Maintenance a Factor
85	Improper Parked Vehicle a Factor
86	Fixed Objects a Factor
87	Slippery Surface a Factor
88	Waterpooling a Factor
89	Other Environmental Factors Involved
90	Type of Vehicle Unit 1
91	Type of Vehicle Unit 2
92	Type of Vehicle Unit 3
93	Pre-Accident Vehicle Action Unit 1
94	Pre-Accident Vehicle Action Unit 2
95	Pre-Accident Vehicle Action Unit 3
96	Type of Accident-2nd Event Unit 1
97	Type of Accident-2nd Event Unit 2
98	Type of Accident-2nd Event Unit 3
99	Human Contributing Factor Unit 1
100	Human Contributing Factor Unit 2
101	Human Contributing Factor Unit 3
102	Vehicular Contributing Factor Unit 1
103	Vehicular Contributing Factor Unit 2
104	Vehicular Contributing Factor Unit 3
105	Environmental Contributing Factor Unit 1
106	Environmental Contributing Factor Unit 2
107	Environmental Contributing Factor Unit 3
108	Number of Occupants Unit 1
109	Number of Occupants Unit 2
110	Number of Occupants Unit 3
111	Vehicle Make Unit 1
112	Vehicle Make Unit 2

113	Vehicle Make Unit 3
114	NCIC Vehicle Type Unit 1
115	NCIC Vehicle Type Unit 2
116	NCIC Vehicle Type Unit 3
117	Model Year Unit 1
118	Model Year Unit 2
119	Model Year Unit 3
120	State, Vehicle Registered Unit 1
121	State, Vehicle Registered Unit 2
122	State, Vehicle Registered Unit 3
123	State, Operators License Driver 1
124	State, Operators License Driver 2
125	State, Operators License Driver 3
126	Operator Restriction Code Driver 1
127	Operator Restriction Code Driver 2
128	Operator Restriction Code Driver 3
129	State of Residence Driver 1
130	State of Residence Driver 2
131	State of Residence Driver 3
132	Age, Driver #1
133	Age, Driver #2
134	Age, Driver #3
135	Age, Occupant #1
136	Age, Occupant #2
137	Age, Occupant #3
138	Age, Occupant #4
139	Age, Occupant #5
140	Sex, Driver #1
141	Sex, Driver #2
142	Sex, Driver #3
143	Sex, Occupant #1
144	Sex, Occupant #2
145	Sex, Occupant #3
146	Sex, Occupant #4
147	Sex, Occupant #5
148	Type of Person, Driver #1
149	Type of Person, Driver #2
150	Type of Person, Driver #3
151	Type of Person, Occupant #1
152	Type of Person, Occupant #2
153	Type of Person, Occupant #3
154	Type of Person, Occupant #4
155	Type of Person, Occupant #5
156	Injury Classification, Driver #1
157	Injury Classification, Driver #2
158	Injury Classification, Driver #3
159	Injury Classification, Occupant #1
160	Injury Classification, Occupant #2
161	Injury Classification, Occupant #3
162	Injury Classification, Occupant #4
163	Injury Classification, Occupant #5
164	Injury Location, Driver #1
165	Injury Location, Driver #2
166	Injury Location, Driver #3
167	Injury Location, Occupant #1
168	Injury Location, Occupant #2

169	Injury Location, Occupant #3
170	Injury Location, Occupant #4
171	Injury Location, Occupant #5
172	Safety Equipment Worn, Driver #1
173	Safety Equipment Worn, Driver #2
174	Safety Equipment Worn, Driver #3
175	Safety Equipment Worn, Occupant #1
176	Safety Equipment Worn, Occupant #2
177	Safety Equipment Worn, Occupant #3
178	Safety Equipment Worn, Occupant #4
179	Safety Equipment Worn, Occupant #5
180	Ejected from Vehicle, Driver #1
181	Ejected from Vehicle, Driver #2
182	Ejected from Vehicle, Driver #3
183	Ejected from Vehicle, Occupant #1
184	Ejected from Vehicle, Occupant #2
185	Ejected from Vehicle, Occupant #3
186	Ejected from Vehicle, Occupant #4
187	Ejected from Vehicle, Occupant #5
188	Vehicle Occupied, Occupant #1
189	Vehicle Occupied, Occupant #2
190	Vehicle Occupied, Occupant #3
191	Vehicle Occupied, Occupant #4
192	Vehicle Occupied, Occupant #5
193	Seat Position, Occupant #1
194	Seat Position, Occupant #2
195	Seat Position, Occupant #3
196	Seat Position, Occupant #4
197	Seat Position, Occupant #5
198	Age, Pedestrian #1
199	Age, Pedestrian #2
200	Sex, Pedestrian #1
201	Sex, Pedestrian #2
202	Injury Classification, Pedestrian #1
203	Injury Classification, Pedestrian #2
204	Injury Location, Pedestrian #1
205	Injury Location, Pedestrian #2
206	Age, Bicyclist
207	Sex, Bicyclist
208	Injury Classification, Bicyclist
209	Injury Location, Bicyclist
210	Identity of Reporting Agency
211	Accident Place Name
212	Citation #1 Issued For
213	Citation #2 Issued For
214	Citation #3 Issued For
215	City Population Group
216	County Population Group
217	Intersection or Segmental Accident
218	Roadway Mileposted

Appendix C.

CRITICAL FREQUENCY OF TOTAL AND EPDO ACCIDENTS

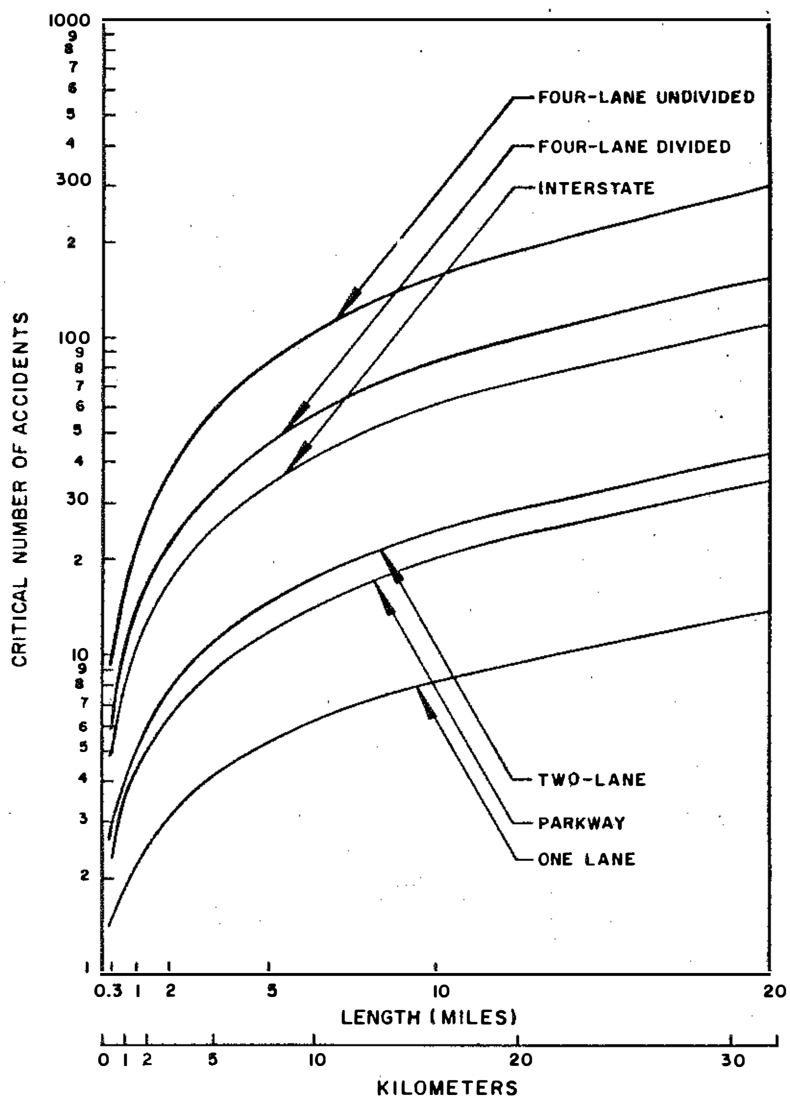

Figure C1. Critical Frequency of Accidents on Rural Highways by Classification and Length of Highway.

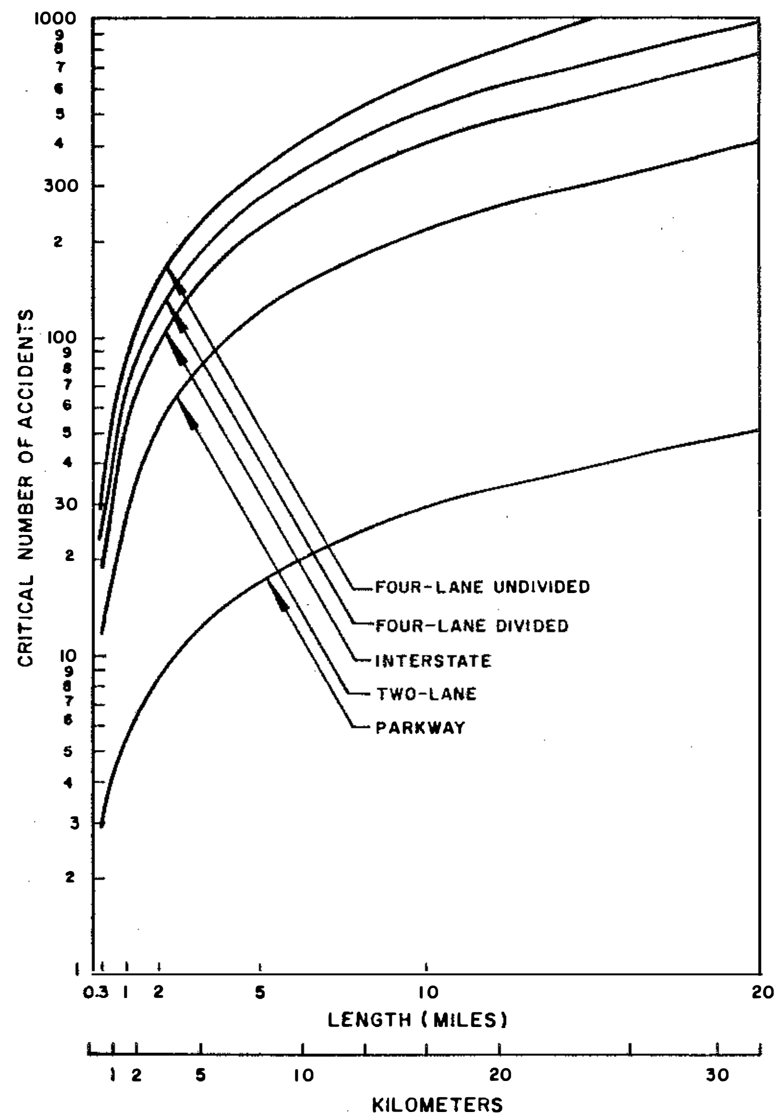

Figure C2. Critical Frequency of Accidents on Urban Streets by Classification and Length of Street.

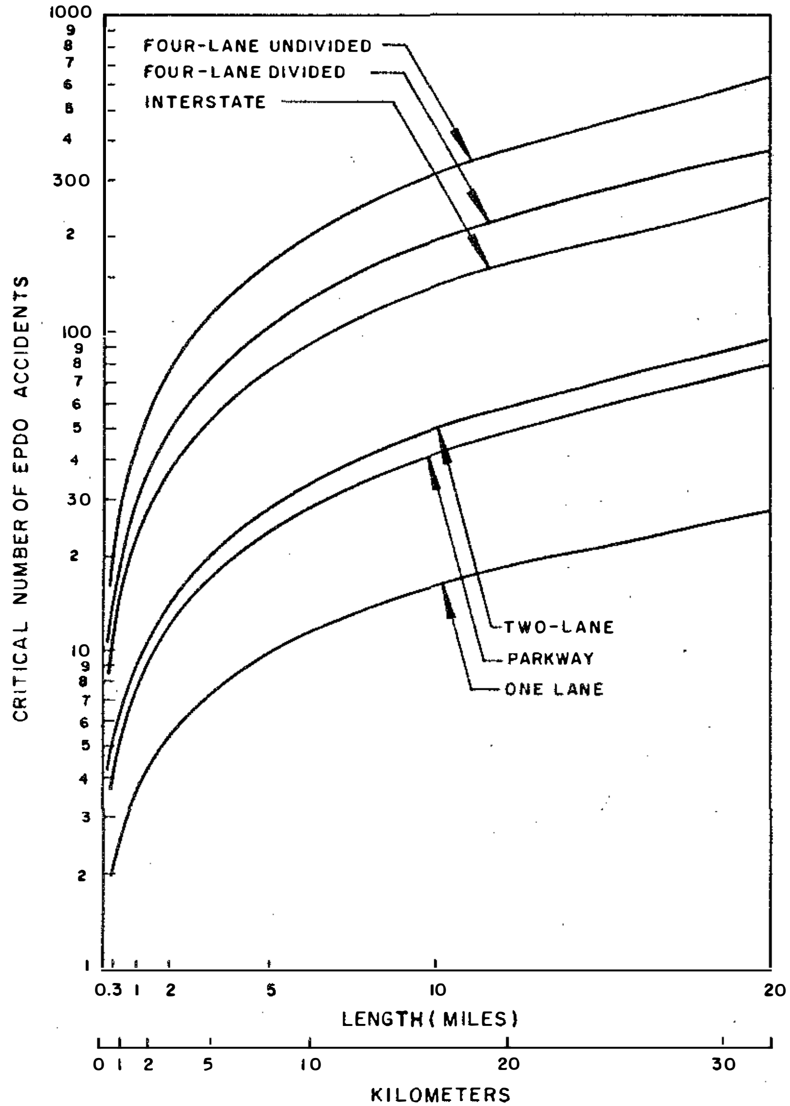

Figure C3. Critical Frequency of EPDO Accidents on Rural Highways by Classification and Length of Highway.

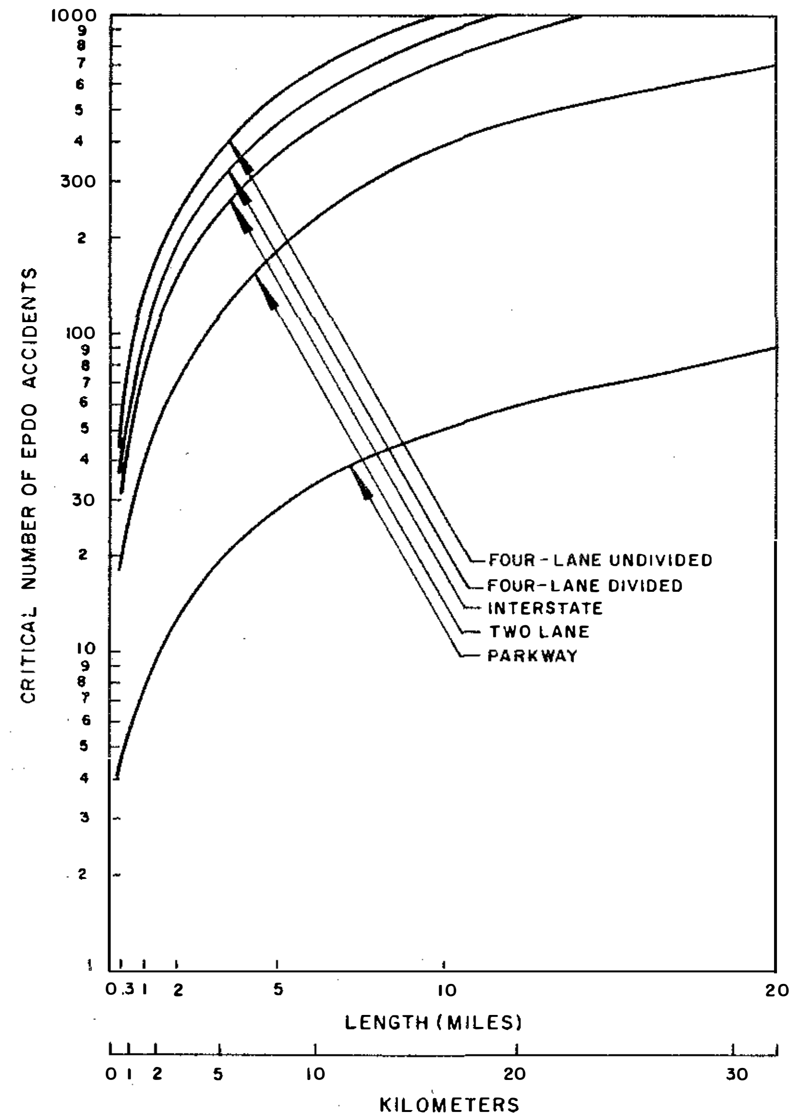

Figure C4. Critical Frequency of EPDO Accidents on Urban Streets by Classification and Length of Street.

Appendix D.

CRITICAL ACCIDENT RATES FOR RURAL HIGHWAY SECTIONS

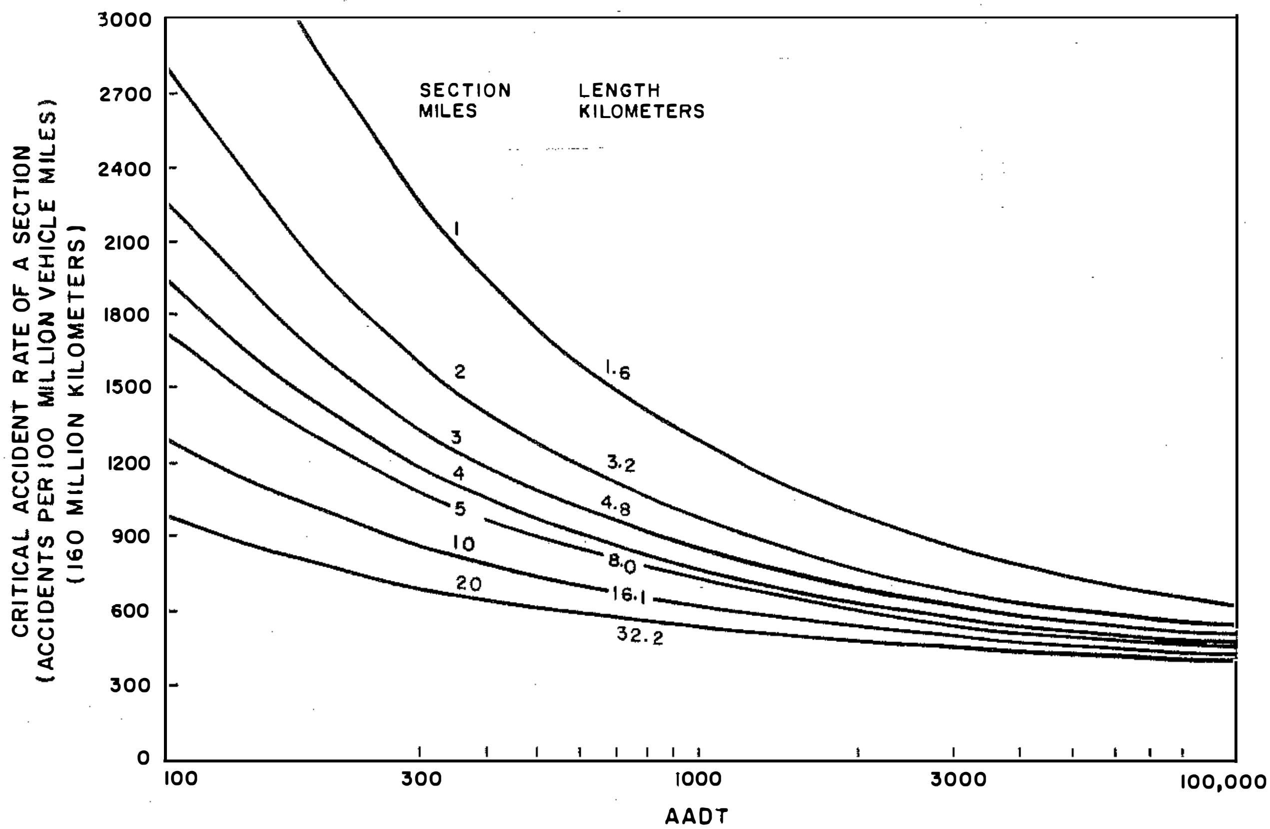

Figure D1. Critical Accident Rates for Rural, One-Lane Highway Sections (One-Year Data) (P=99.5).

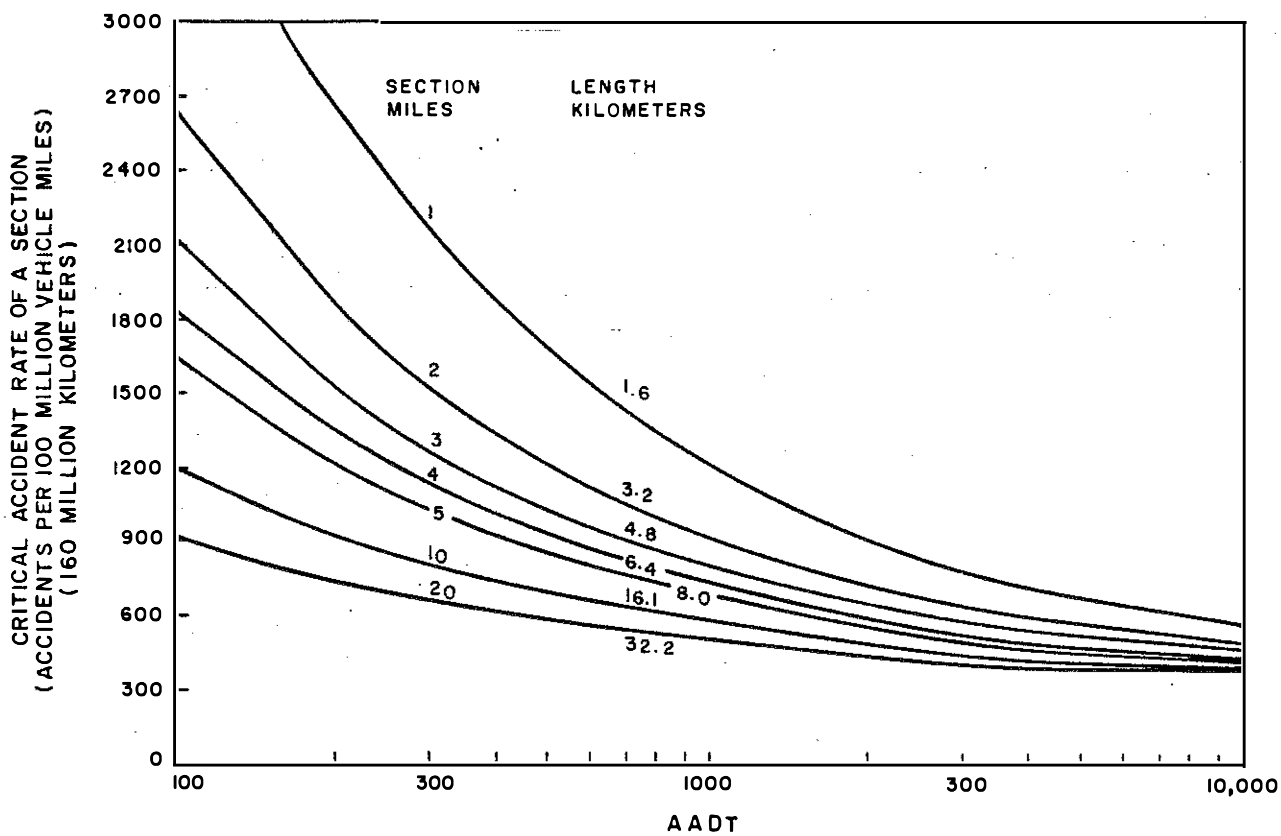

Figure D2. Critical Accident Rates for Rural, Two-Lane Highway Sections (One-Year Data) (P=99.5).

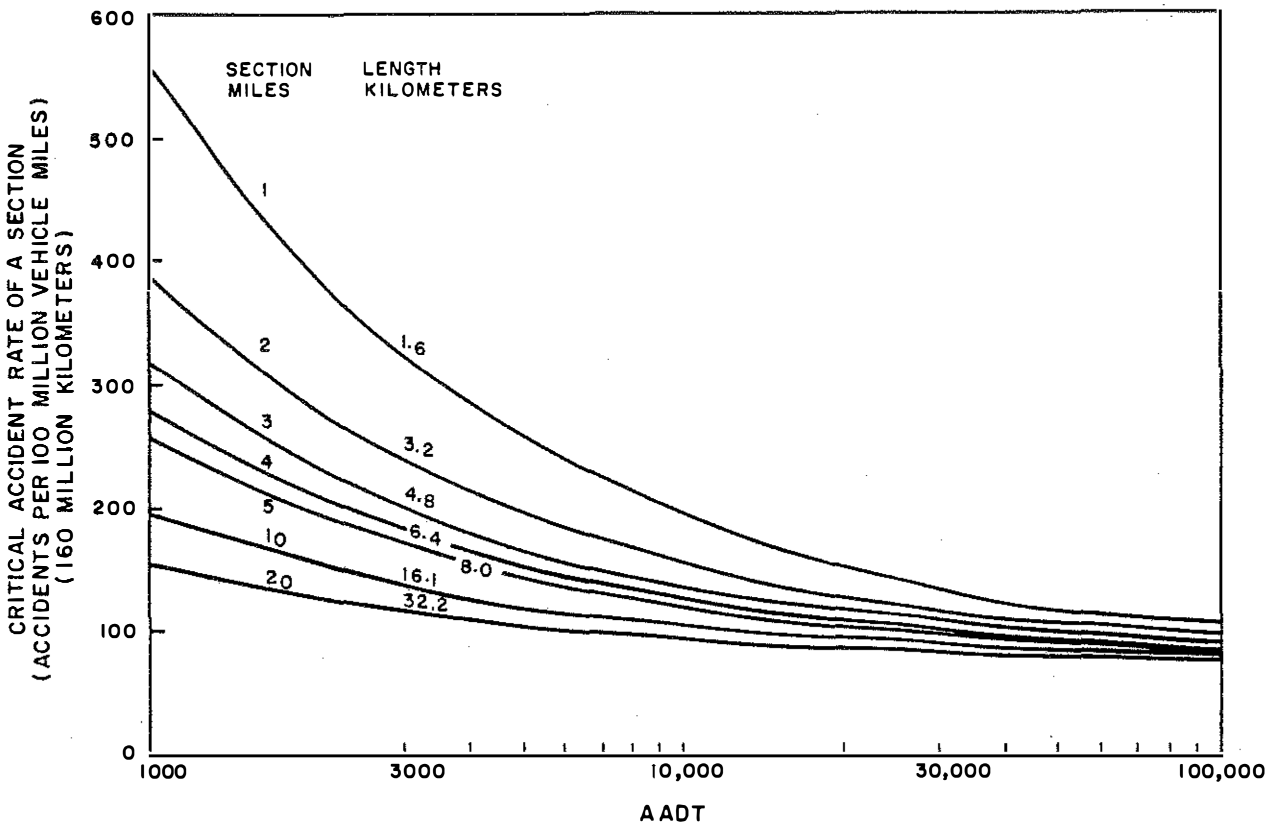

Figure D3. Critical Accident Rates for Rural, Interstate Highway Sections (One-Year Data) (P=99.5).

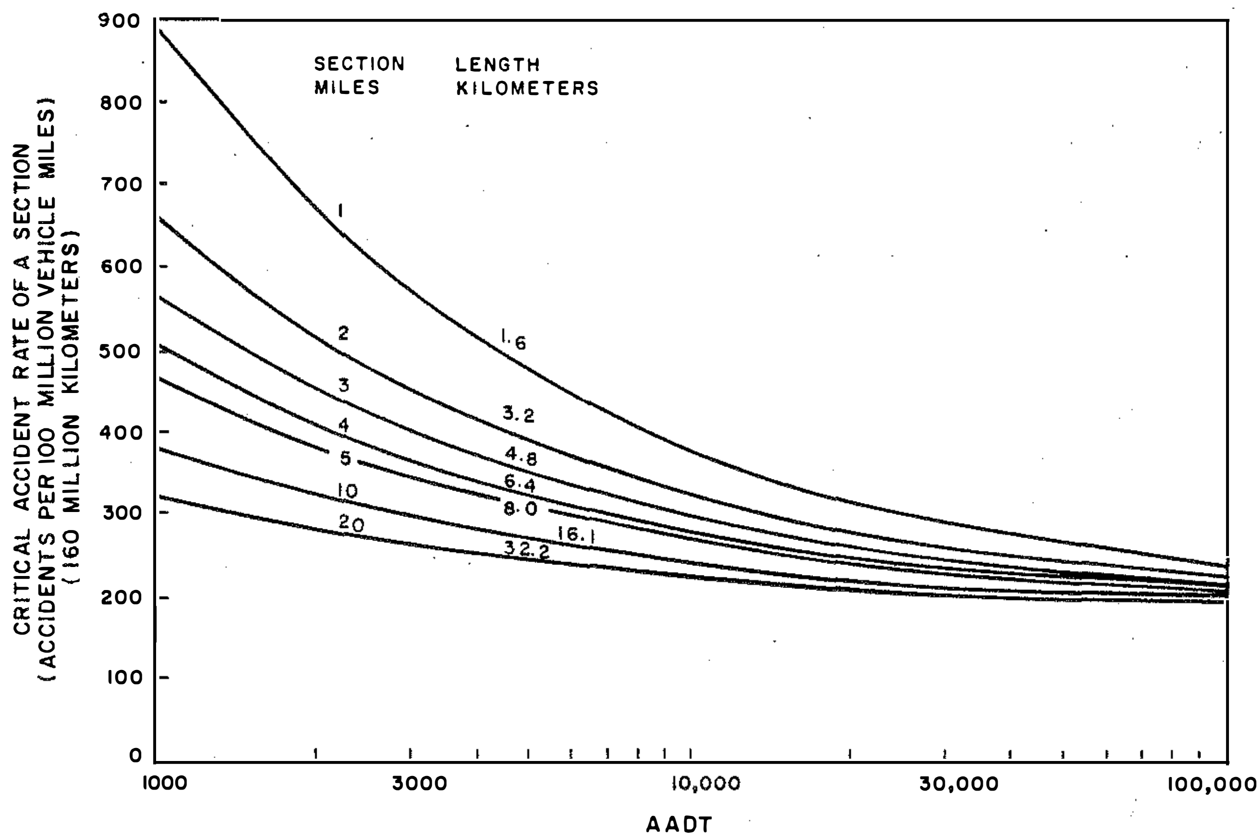

Figure D4. Critical Accident Rates for Rural, Four-Lane, Divided Highway Sections (One-Year Data) (P=99.5).

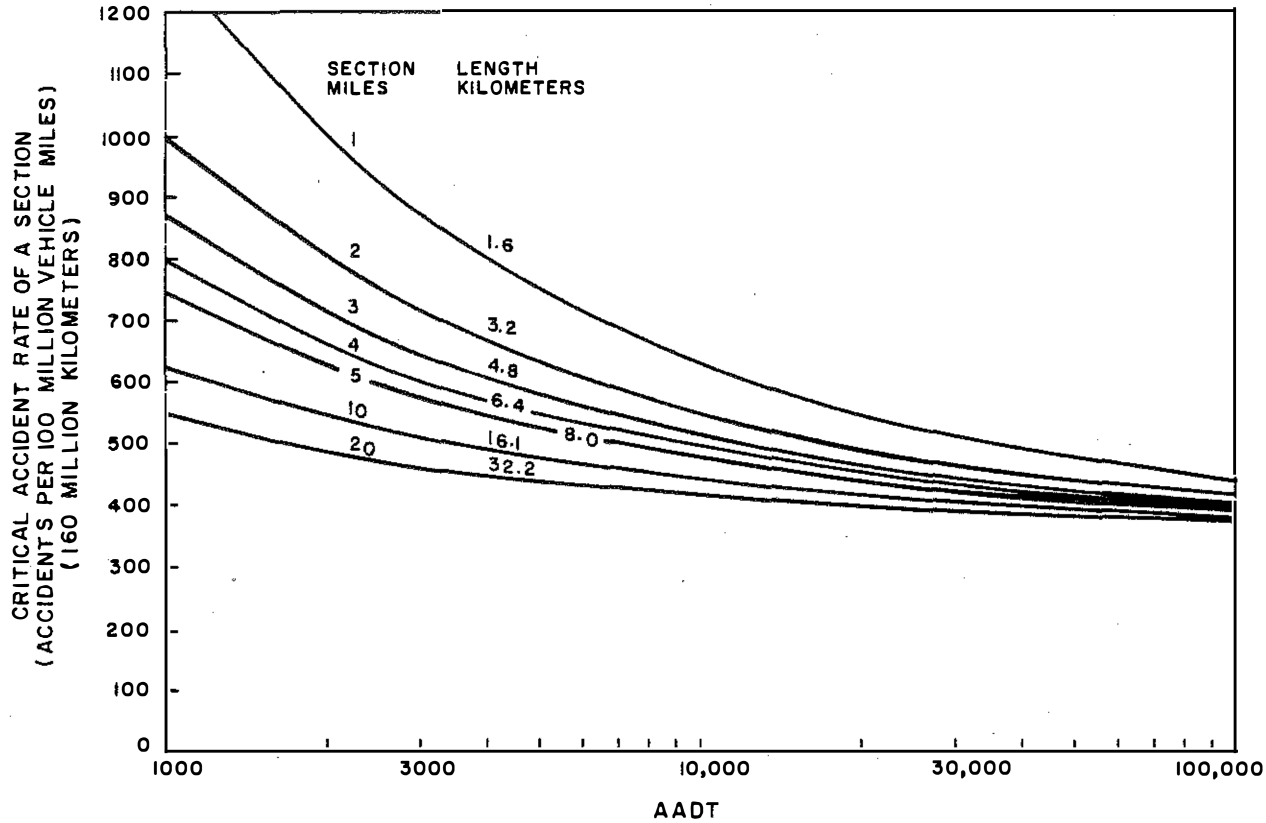

Figure D5. Critical Accident Rates for Rural, Four-Lane, Undivided Highway Sections (One-Year Data) (P=99.5).

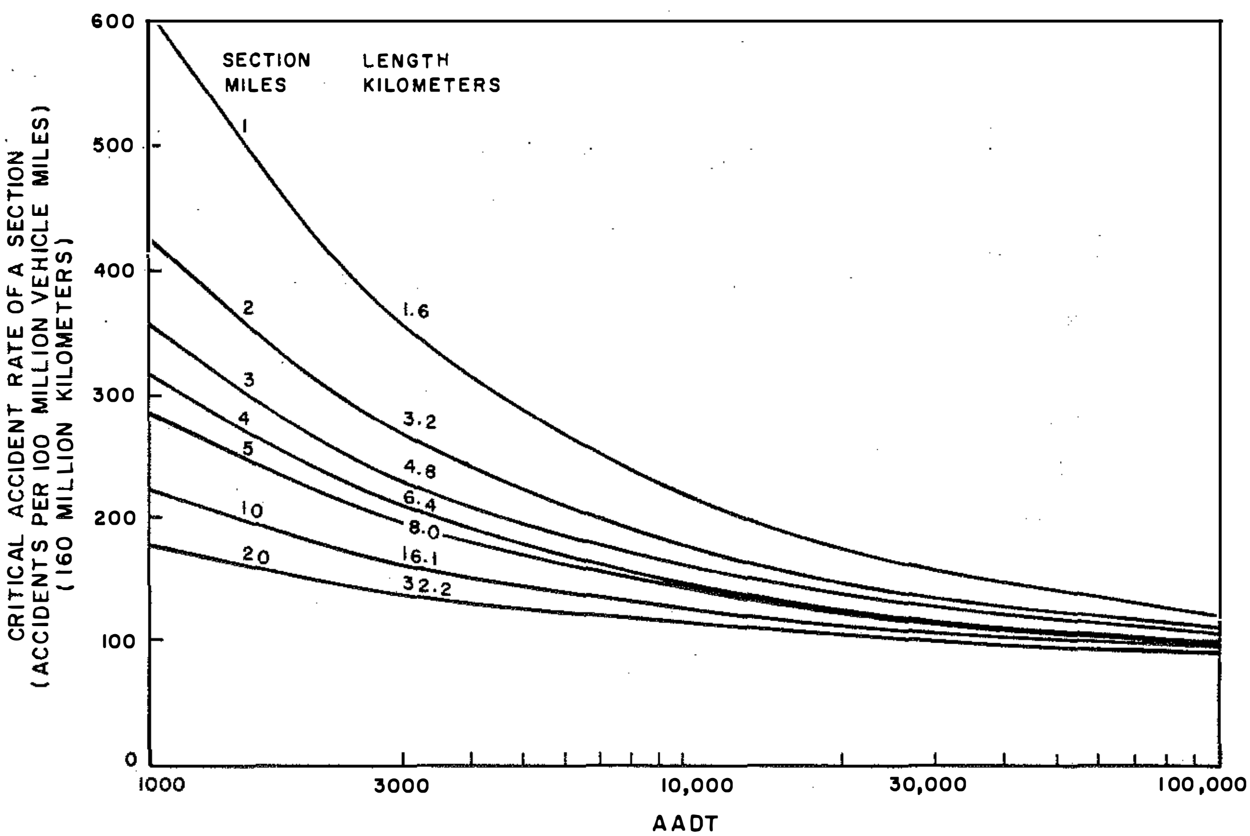

Figure D6. Critical Accident Rates for Rural, Toll Road, Highway Sections (One-Year Data) (P=99.5).

Appendix E.

HIGH-ACCIDENT LOCATION PROGRAM SOURCE DECK

```
 IDENTIFICATION DIVISION.
        SKIP1
 PROGRAM-ID.          RN85DR04.
        SKIP3
 AUTHOR.              DANIEL T. REFFETT
                      INSTRUMENTATION, SYSTEMS, AND COMPUTATION SECT.
 INSTALLATION.        KENTUCKY DEPARTMENT OF TRANSPORTATION
                      DIVISION OF RESEARCH
                      533 SOUTH LIMESTONE STREET
                      LEXINGTON, KENTUCKY 40508.
 DATE-WRITTEN.        JULY  , 1977.
*DATE-MODIFIED.       FEB. 17, 1978.
 DATE-COMPILED.
        EJECT
 REMARKS.             THE PURPOSE OF THIS PROGRAM IS TO LOCATE HIGH
                      ACCIDENT AREAS ON KENTUCKY'S RURAL HIGHWAYS.
        SKIP1
                      SYSTEMS AFFECTED: NONE.
        SKIP1
                      FILES AFFECTED: NONE.
        SKIP1
                      I/O: INPUT FOR THIS PROGRAM IS FROM 2 FILES: (1)
                      A CARD FILE WHICH SUPPLIES A CRITICAL NUMBER
                      AND A MILEPOST INCREMENT, WHICH, INCIDENTALLY
                      MAY BE CHANGED ACCORDING TO THE INDIVIDUAL
                      USER'S NEEDS, AND (2) A DISK FILE WHICH WAS
                      PREPARED BY THE RN85DR03 PROGRAM PRIOR TO RUN-
                      NING THIS JOB. THE OUTPUT CONSISTS OF DATA
                      WHICH IS WRITTEN ONTO A TEMPORARY WORKSPACE
                      TO BE USED IN THE NEXT STEP OF THIS JOB. THIS
                      FILE INCLUDES THE HAZARDOUS LOCATIONS WITH
                      THEIR RESPECTIVE NUMBER OF ACCIDENTS AND
                      CALCULATED EPDO.
        SKIP1
                      JCL: THIS PROGRAM HAS NOT BEEN CATALOGUED SO THE
                      ONLY JCL NECESSARY IS THE STANDARD IBM OS JCL
                      FOR THE FILES MENTIONED IN THE I/O SECTION
                      ABOVE. THIS PROGRAMMER USES THE FOLLOWING:
        SKIP1
                      CC1
                      I
                      (FOR THE CARD FILE)
                      //GO.SYSIN DD *
        SKIP1
                      (FOR THE INPUT DISK)
                      //GO.DISKIN DD UNIT=3350,VOL=SER=WORK03,
                          DSN=TT.N85DI,DISP=(OLD,KEEP),
                          SPACE=(CYL,(4,1)),
                          DCB=(RECFM=FB,LRECL=015,BLKSIZE=7500)
        SKIP1
                      (FOR THE OUTPUT DISK)
                      //GO.DISKOUT DD UNIT=SYSDA,DSN=&&N85D2,
                          DISP=(NEW,PASS),SPACE=(CYL,(4,1)),
                          DCB=(RECFM=FB,LRECL=50,BLKSIZE=5000)
        SKIP1
                      SUBROUTINES CALLED: NONE.
        EJECT
                      REFERENCES:  PROJECT DOCUMENTATION CAN BE FOUND
                      IN THE N-85 FILE UNDER RN85DR04, HOWEVER, A
                      BRIEF DESCRIPTION FOLLOWS:
        SKIP1
                      THIS PROGRAM READS THE DATA PREPARED BY THE
                      RN85DR03 JOB AND SEARCHES IT TO FIND CRITICAL
                      LOCATIONS. THE SELECTION OF THESE LOCATIONS IS
                      DETERMINED BY THE ONE-CARD CARD FILE. THIS CARD
                      GIVES THE LENGTH OF A SECTION TO BE INVESTIGATED
                      AND THE NUMBER OF ACCIDENTS NECESSARY TO EXHIBIT
                      A CRITICAL LOCATION. (CODING INSTRUCTIONS FOR
                      THIS CARD IS GIVEN IN THE DATA ENTRY SECTION BE-
                      LOW). WHEN A HIGH ACCIDENT LOCATION IS FOUND,
                      AN ESTIMATED PROPERTY DAMAGE ONLY (EPDO) VALUE
                      FOR THAT LOCATION AS WELL AS THE COUNTY, ROUTE,
                      BEGINNING AND ENDING MILEPOSTS, NUMBER OF LANES
                      AND NUMBER OF ACCIDENTS FOR THAT LOCATION ARE
                      OUTPUT TO A TEMPORARY WORKSPACE. THIS WORKSPACE
                      IS THEN IN TURN UTILIZED BY THE SECOND STEP OF
                      THIS JOB.
        SKIP2
                      DATA ENTRY INSTRUCTIONS: THE ONLY DATA ENTRIES
                      NECESSARY ARE FOR CODING THE ONE-CARD CARD FILE,
                      CALLED THE LIMIT CARD IN THE PROGRAM. THE LENGTH
                      OF HIGHWAY TO BE CHECKED CAN BE ANY NUMBER FROM
                      0.1 MILES TO 99.9 MILES. HOWEVER, THE DECIMAL
                      POINT IS IMPLIED AND SHOULD NOT BE PHYSICALLY
                      CODED ON THE CARD. THEREFORE, A SECTION OF 0.1
                      MILES WOULD BE CODED AS 001 AND A SECTION OF
                      99.9 WOULD BE CODED AS 999. THE NUMBER OF ACCID-
                      ENTS FIELD CAN CONTAIN ANY INTEGER VALUE FROM
                      1 TO 999 AND SHOULD BE RIGHT SHIFTED WHEN CODED.
        SKIP1
                         NAME           COBOL PICTURE     CARD COLUMNS
                         ----           -------------     ------------
        SKIP1
                       SECTION LENGTH      99V9              1- 3
        SKIP1
                       CRITICAL NUMBER     999               5- 7
        SKIP1
        SKIP1
                      OPERATIONS: NONE.
        EJECT
*
*                  VARIABLE LIST FOR TP-RECORD
*
*
*            CC                                 COUNTY CODE
*
*            RT                                 ROUTE
*
*            MP                                 MILEPOST
*
*            NL                                 NUMBER OF LANES
*
*            AS                                 ACCIDENT SEVERITY
*
*
*
*            VARIABLE LIST FOR WORKING STORAGE SECTION
*                       ( LEVEL 77 ITEMS )
*
*
*            A-KTR                              COUNTER FOR INCAPACIT-
*                                               ATING ACCIDENTS
*
*            ACC-KTR                            THE NUMBER OF ACCIDENTS
*                                               OCCURING AT A LOCATION.
*
*            B-KTR                              COUNTER FOR NON-INCAP-
*                                               ACITATING ACCIDENTS
*
*            C-KTR                              COUNTER FOR POSSIBLE
*                                               INJURY ACCIDENTS
*
*            DP-SECLTH                          THE SECTION LENGTH OF
*                                               HIGHWAY TO BE INVEST-
*                                               IGATED, FOR DISPLAY
*                                               PURPOSES.
*
*            F-KTR                              COUNTER FOR FATAL AC-
*                                               CIDENTS
*
*            J                                  USED AS A SUBSCRIPT
*
*            MP-SECLTH                          THE SECTION LENGTH OF
*                                               HIGHWAY TO BE INVEST-
*                                               IGATED, FOR USE BY THE
*                                               PROGRAM.
*
*            PDO-KTR                            COUNTER FOR PROPERTY
*                                               DAMAGE ONLY ACCIDENTS,
*                                               WHICH INCLUDES THOSE
*                                               NOT STATED.
*
*            MP-LIMIT                           THIS IS THE HIGH MILE-
*                                               POST LIMIT WHICH IS
*                                               COMPUTED BY ADDING A
*                                               CONSTANT, IN THIS CASE
*                                               0.2 TO THE MILEPOST.
*
*            NL                                 LEAST NUMBER OF LANES
*
*            SAVE-CC                            STORED COUNTY CODE
*
*            SAVE-MP                            STORED MILEPOST
*
*            SAVE-RT                            STORED ROUTE.
*
*            WS-CRITNO                          NUMBER OF ACCIDENTS
*                                               NECESSARY FOR A CRIT-
*                                               ICAL ACCIDENT.
*
*            WS-EPDO                            ESTIMATED PROPERTY DAM-
*                                               AGE ONLY
*
        EJECT
 ENVIRONMENT DIVISION.
 CONFIGURATION SECTION.
 SOURCE-COMPUTER. IBM-370.
 OBJECT-COMPUTER. IBM-370.
 INPUT-OUTPUT SECTION.
 FILE-CONTROL.
        SELECT CARD-FILE ASSIGN TO UT-S-SYSIN.
        SELECT ACCI-FILE ASSIGN TO UT-3330V-S-DISKIN.
        SELECT HAZL-FILE ASSIGN TO UT-SYSDA-S-DISKOUT.
        EJECT
 DATA DIVISION.
 FILE SECTION.
        SKIP2
 FD     CARD-FILE
        LABEL RECORDS ARE OMITTED
        RECORD CONTAINS 80 CHARACTERS
        DATA RECORD IS LIMIT-CARD.
*
*          THIS IS THE FORMAT FOR THE INPUT DATA CARD FILE.
*
 01     LIMIT-CARD.
        02  LC-SECLTH              PIC         99V9.
        02  FILLER                 PIC         X.
        02  LC-CRITNO              PIC         999.
        02  FILLER                 PIC         X(73).
 01     LC-X REDEFINES LIMIT-CARD  PIC         X(80).
        SKIP2
 FD     ACCI-FILE
       BLOCK CONTAINS 868 RECORDS
        RECORD CONTAINS 15 CHARACTERS
        LABEL RECORDS ARE STANDARD
        DATA RECORD IS TP-RECORD.
*
*          FILE LAYOUT FOR DATA SET TT.N85DI PRODUCED BY PROGRAM
*          RN85DR03 USED AS INPUT TO THIS PROGRAM.
*
 01     TP-RECORD.
        02  CC  PIC 999.
        02  RT  PIC X(5).
        02  MP  PIC 999V9.
        02  NL  PIC 99.
        02  AS  PIC 9.
        SKIP2
*  HAZARDOUS LOCATION FILE
```

```
FD  HAZL-FILE
    LABEL RECORDS ARE STANDARD
    RECORD CONTAINS 50 CHARACTERS
    BLOCK CONTAINS 100 RECORDS
    DATA RECORD IS LOCATION-RECORDS.
01  LOCATION-RECORDS             PIC         X(50).
    SKIP2
WORKING-STORAGE SECTION.
77  A-KTR        PIC      9(2),   VALUE   ZEROES.
77  ACC-KTR      PIC      9(5).   VALUE   ZEROES.
77  B-KTR        PIC      9(2),   VALUE   ZEROES.
77  C-KTR        PIC      9(2),   VALUE   ZEROES.
77  DP-SECLTH    PIC      99.9,   VALUE   ZEROES.
77  F-KTR        PIC      9(2),   VALUE   ZEROES.
77  J   PIC  99,  VALUE ZEROES.
77  LINE-CT      PIC      9(2),   VALUE   ZEROES.
77  PDO-KTR      PIC      9(3),   VALUE   ZEROES.
77  MP-LIMIT     PIC   999V999,   VALUE   ZEROES.
77  MP-SECLTH    PIC      99V9,   VALUE   ZEROES.
77  NLL PIC  99,  VALUE ZEROES.
77  NLOC PIC 99,  VALUE ZEROES.
77  SAVE-CC      PIC      9(3),   VALUE   ZEROES.
77  SAVE-MP      PIC   999V999,   VALUE   ZEROES.
77  SAVE-RT      PIC      X(5),   VALUE   SPACES.
77  WS-CRITNO    PIC      9(3),   VALUE   ZEROES.
77  WS-EPDO      PIC   9999V99,   VALUE   ZEROES.
01  ARRAY.
    02  NLO PIC 99, OCCURS 6 TIMES.
*
*        FILE LAYOUT FOR DATA SET &&N8502 PRODUCED AND OUTPUT
*        FROM THIS PROGRAM AND WILL LATER BE USED AS INPUT FOR
*        PROGRAM RN85DR05 TO BE MATCHED WITH MAINTENANCE TAPE DATA
*        TO ACQUIRE TRAFFIC VOLUMES.
*
01  WS-LOCA-RECORDS.
    02  LR-CO                  PIC        9(3),     VALUE ZEROES.
    02  FILLER                 PIC        X,        VALUE SPACE.
    02  LR-ROUTE               PIC        X(5),     VALUE SPACES.
    02  FILLER                 PIC        X,        VALUE SPACE.
    02  LR-BMP                 PIC        999V999,  VALUE ZEROES.
    02  FILLER                 PIC        X,        VALUE SPACE.
    02  LR-EMP                 PIC        999V999,  VALUE ZEROES.
    02  FILLER                 PIC        X,        VALUE SPACE.
    02  LR-NACC                PIC        9(5),     VALUE ZEROES.
    02  FILLER                 PIC        X,        VALUE SPACE.
    02  LR-NL                  PIC        99,       VALUE ZEROES.
    02  FILLER                 PIC        X,        VALUE SPACE.
    02  LR-EPDO                PIC        9999V99,  VALUE ZEROES.
    02  FILLER                 PIC        X(11),    VALUE SPACES.
    EJECT
PROCEDURE DIVISION.
HOUSEKEEPING SECTION.
    OPEN INPUT CARD-FILE, ACCI-FILE,
         OUTPUT HAZL-FILE.
    PERFORM SET-LIMITS.
*
MAINLINE SECTION.
    PERFORM READ-RT1 THRU AS-INC-RT.
    PERFORM READ-RT2.
    EJECT
*
READ-RT1.
    READ ACCI-FILE AT END GO TO EOJ.
*
SAVE-VARIABLE-RT.
    PERFORM CLEAR-ARRAY-RT THRU EXIT-2 VARYING J FROM 1 BY 1
         UNTIL J > 6.
    MOVE RT TO SAVE-RT.
    MOVE CC TO SAVE-CC.
    MOVE MP TO SAVE-MP.
    COMPUTE MP-LIMIT = SAVE-MP + MP-SECLTH.
*
AS-INC-RT.
    IF NL > 0 AND NL < 7, MOVE NL TO J.
    IF NL > 0 AND NL < 7, ADD 1 TO NLO (J).
    ADD 1 TO ACC-KTR.
    IF AS = 1, ADD 1 TO F-KTR.
    IF AS = 2, ADD 1 TO A-KTR.
    IF AS = 3, ADD 1 TO B-KTR.
    IF AS = 4, ADD 1 TO C-KTR.
    IF AS = 0 OR AS > 4, ADD 1 TO PDO-KTR.
*
READ-RT2.
    READ ACCI-FILE AT END GO TO EOJ.
    IF RT NOT = SAVE-RT
         OR MP < SAVE-MP OR MP > MP-LIMIT,
         GO TO COMPARE-ACC-KTR-RT,
         ELSE GO TO AS-INC-RT.
*
COMPARE-ACC-KTR-RT.
    IF ACC-KTR IS < WS-CRITNO, GO TO CLEAR-VARIABLE-RT.
    EJECT
CALC-EPDO-RT.
    COMPUTE NLL = 1.
    MOVE NLO ( 1 ) TO NLOC.
    PERFORM CHECK-RT THRU EXIT-1 VARYING J FROM 2 BY 1
         UNTIL J > 6.
    COMPUTE WS-EPDO = 9.5 * ( A-KTR + F-KTR )
         + 3.5 * ( B-KTR + C-KTR ) + PDO-KTR.
    MOVE SPACES TO LOCATION-RECORDS.
    MOVE SAVE-CC TO LR-CO.
    MOVE SAVE-RT TO LR-ROUTE.
    MOVE SAVE-MP TO LR-BMP.
    MOVE MP-LIMIT TO LR-EMP.
    MOVE ACC-KTR TO LR-NACC.
    MOVE WS-EPDO TO LR-EPDO.
    MOVE NLL TO LR-NL.
    WRITE LOCATION-RECORDS FROM WS-LOCA-RECORDS.
    EJECT
CLEAR-VARIABLE-RT.
    MOVE ZEROES TO ACC-KTR, A-KTR, B-KTR, C-KTR, F-KTR,
         PDO-KTR, WS-EPDO.
    GO TO SAVE-VARIABLE-RT.
*
CHECK-RT.
    IF NLO (J) < NLOC OR NLO (J) = NLOC, GO TO EXIT-1.
    COMPUTE NLOC = NLO ( J ).
    COMPUTE NLL = J.
*
EXIT-1.
    EXIT.
*
CLEAR-ARRAY-RT.
    MOVE ZEROES TO NLO (J).
*
EXIT-2.
    EXIT.
*
SET-LIMITS.
    READ CARD-FILE AT END GO TO EOJ.
    EXAMINE LC-X REPLACING ALL ' ' BY '0'.
   COMPUTE MP-SECLTH = LC-SECLTH - .1.
    MOVE LC-CRITNO TO WS-CRITNO.
    MOVE LC-SECLTH TO DP-SECLTH.
    DISPLAY '  NUMBER OF ACCIDENTS TO BE CRITICAL = ' WS-CRITNO.
    DISPLAY ' SECTION LENGTH CONSIDERED = ' DP-SECLTH.
*
EOJ.
   CLOSE ACCI-FILE, CARD-FILE,
         HAZL-FILE.
   STOP RUN.
```

Appendix F.

CRITICAL ACCIDENT RATES FOR URBAN SECTIONS

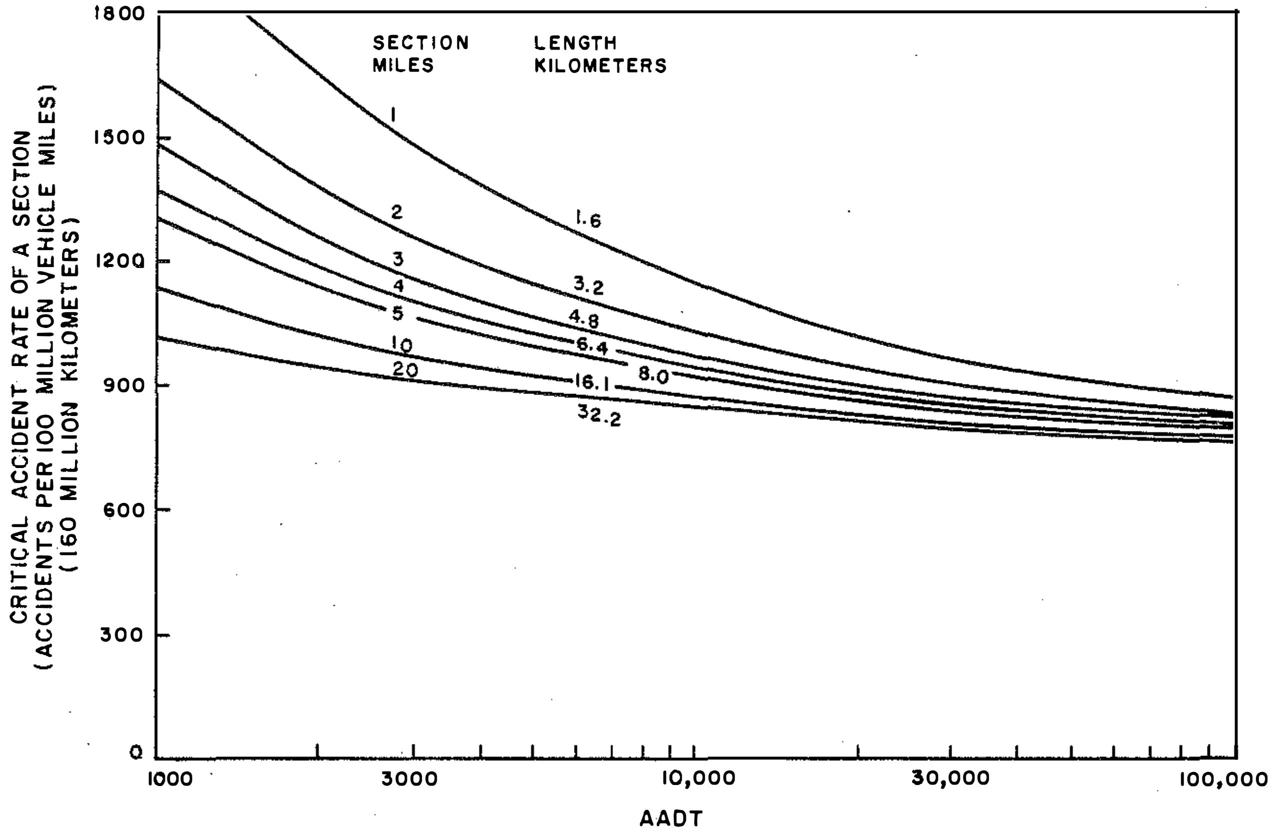

Figure F1. Critical Accident Rates for Urban, Two-Lane Highway Sections (One-Year Data) (P=99.5).

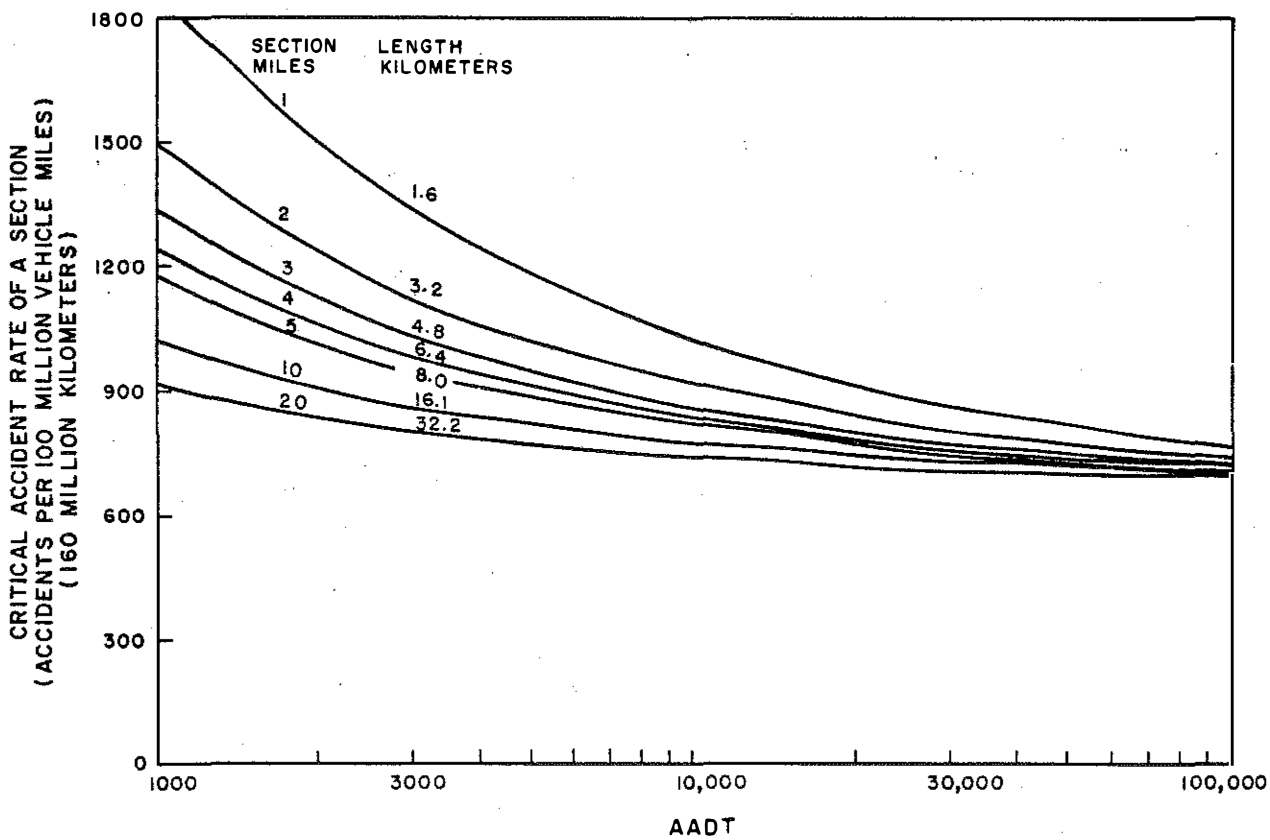

Figure F2. Critical Accident Rates for Urban, Four-Lane, Divided (No Access Control) Highway Sections (One-Year Data) (P=99.5).

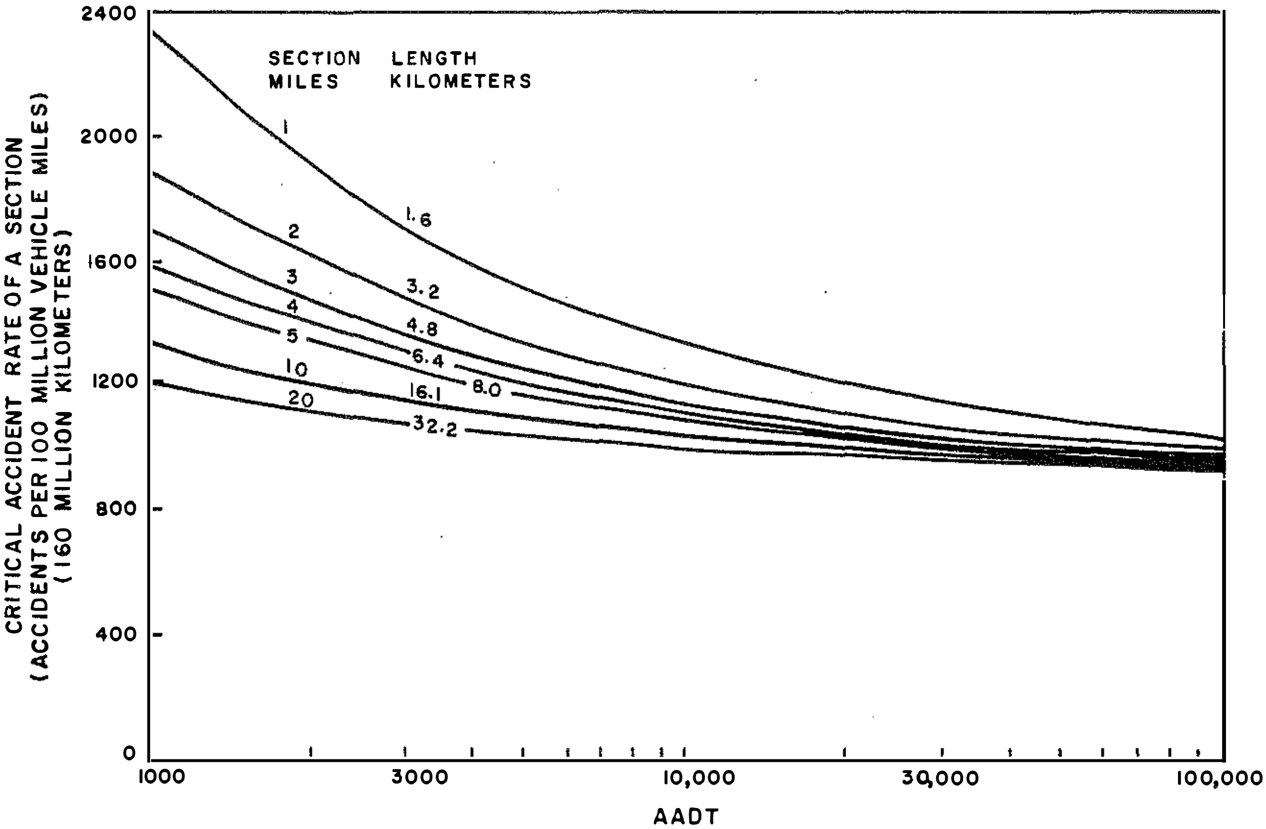

Figure F3. Critical Accident Rates for Urban, Four-Lane, Undivided Highway Sections (One-Year Data)(P=99.5).

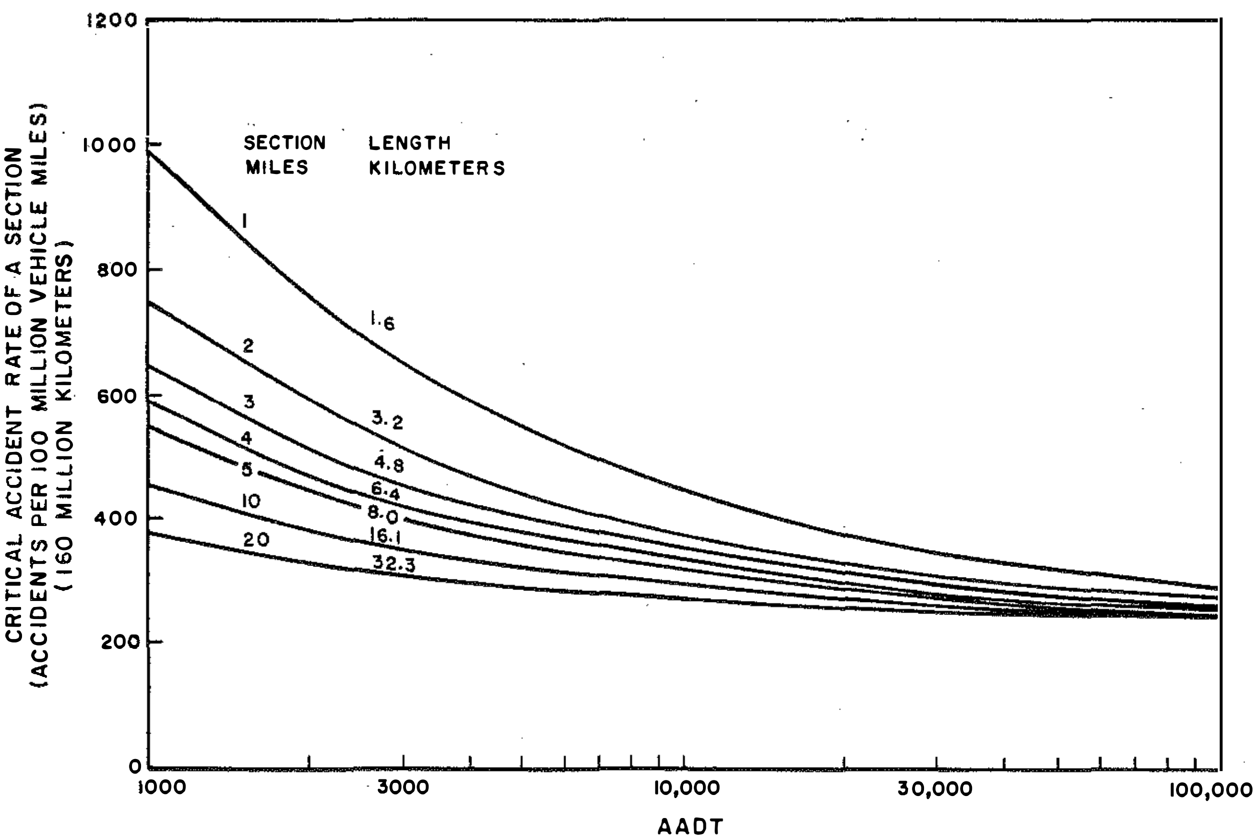

Figure F4. Critical Accident Rates for Urban, Interstate Highway Sections (One-Year Data) (P=99.5).

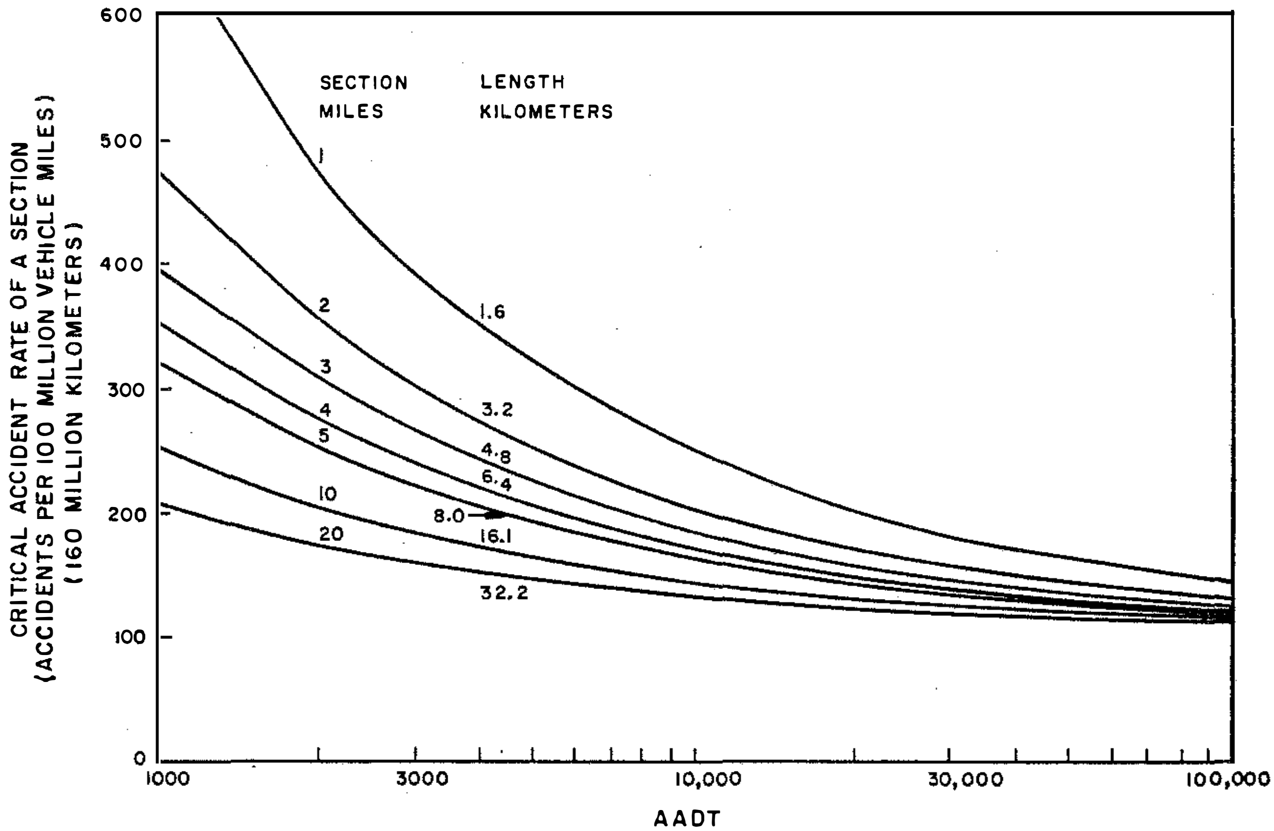

Figure F5. Critical Accident Rates for Urban, Toll Road Highway Sections (One Year Data) (P=99.5).

Appendix G.

KENTUCKY'S TRAFFIC CONFLICT PROCEDURE

Kentucky's Traffic Conflict Procedure

DATA COLLECTION PROCEDURE

A traffic conflicts survey is the systematic surveillance of major intersection approach legs. An intersection approach leg is any one of the roadways converging and intersecting. At most intersections, conflict data should be collected on the two major approach legs. Where two major arterials intersect, data should be collected on all four legs. At T-intersections, the third leg is usually excluded from data collection.

The survey team consists of from one to three trained observers. Volume counts should be made with traffic counters for all movements of all approaches separately at a location near the intersection. It may sometimes be necessary to collect volume data for the same periods on another day. Conflict data should be collected by two observers, each positioned on a major approach about 100 to 300 feet (30 to 90 m) back from the intersection so vehicle brakelights can be seen. Observers may sit in state-owned vehicles parked on the road shoulder facing traffic or sit in chairs at urban intersections where sidewalks exist.

Data should normally be collected on a Tuesday, Wednesday, or Thursday for two or three hours when traffic is at or near peak volumes. For a two-hour count, data should normally be collected during the morning (7:30 to 8:30 a.m.) and the afternoon (4:30 to 5:30 p.m.) rush hours. If more data can be collected, other times may include noontime rush (11:30 a.m. to 12:30 p.m.) or other afternoon periods (3:30 to 4:30 p.m.). At intersections near shopping centers, data should be collected for periods near the closing time. In situations where weekend volumes are critical, data should be collected on those days. In some Kentucky cities, volume data is available for each hour of the day for major intersections. These data should be used to select peak volume times for collection of conflict data.

Conflict data should be collected in 15-minute periods and recorded on the data forms for signalized intersections (Figure G 1) and nonsignalized intersections (Figure G2). Volume data should be recorded every 15 minutes on the volume data sheet. No breaks need to be taken; data are usually collected for only one or possibly two hours at a time. Conflict data should be collected on both approaches simultaneously, if possible. However, conflict counts on the major approach only may be made if another observer is not available.

The major weave and conflict types, which are listed on the data sheets for signalized intersections, are given below.

Weave

A weave vehicle is a situation in which a vehicle changes lanes as it approaches or passes through the intersection. A vehicle which momentarily leaves its lane -- that is, moves to another lane and returns immediately to its original lane -- should be counted as a weave if at least half of the vehicle penetrated the second lane. Count only one weave per vehicle. The cause for repeated weave patterns should be noted on the data sheet. A "weaved-for-left-turn" occurs when an approaching vehicle weaves into the right lane to avoid having to stop for a left-turning vehicle. A "weave-other" occurs when an approaching vehicle weaves for any other reason.

Weave Conflict

A weave-type conflict is defined as a situation in which a vehicle changes lanes into the path of another vehicle, causing the offended vehicle to brake or weave to avoid a collision. The fact that the weave conflict has occurred is evidenced by a brake-light indication or lane change by the offended vehicle.

In a weave conflict, Figure G3, Vehicle 1 weaves and changes lanes, causing Vehicle 2 to brake. As the conflict is viewed from the rear, a brake-light indication can be observed on Vehicle 2. The categories for left-turn result from a weave due to a left-turning vehicle as described previously.

Opposing Left-Turn Conflict

This occurs when a left-turning vehicle crosses directly in front of a through vehicle and causes it to brake or swerve. This conflict is viewed on the approach where the brake lights can be observed (Figure G4).

Ran-Red-Light

This is a situation where a vehicle enters the intersection and crosses the curb-line or stop-bar on a red signal. Vehicles which entered the intersection legally and complete their movement after the signal changes are not considered violators. The left-turning vehicles which ran a red light have been separated from the others (through and right-turners).

Stopped Abruptly

This conflict type occurs when a vehicle makes an unusually quick deceleration during the yellow phase of the signal or cycle or shortly after the red phase appears. Usually, a noticeable dipping of the front end of the vehicle occurs and(or) the screeching of tires is heard in severe cases.

LOCATION ______________ DIRECTION ____________ DATE ____________

	WEAVES		WEAVE CONFLICTS			RUN RED LIGHT											
STARTING TIME	AROUND LEFT TURNER	OTHER	AROUND LEFT TURNER	OTHER	OPPOSING LEFT TURN	TURNING LEFT	STRAIGHT OR RIGHT	ABRUPT STOP	SLOW FOR RIGHT TURN	SLOW FOR LEFT TURN	PREVIOUS LEFT TURN	OTHER PREVIOUS CONFLICT	TRAFFIC BACKUP OR CON-GESTION	SLOW-MOVING VEHICLE	PEDESTRIAN CONFLICT		

1 = Routine; * = Moderate; ⊛ = Severe

Figure G1. Conflict Data Sheet: Signalized Intersections.

LOCATION ______________ DIRECTION __________ DATE __________

STARTING TIME	WEAVES		WEAVE CONFLICTS		OPPOSING LEFT TURN	THROUGH CROSS TRAFFIC		LEFT-TURN CROSS TRAFFIC		RIGHT TURN CROSS TRAFFIC	SLOW FOR RIGHT TURN	SLOW FOR LEFT TURN	PREVIOUS LEFT TURN	OTHER PREVIOUS CONFLICT	TRAFFIC BACKUP OR CON-GESTION	SLOW-MOVING VEHICLE	PEDESTRIAN CONFLICT		
	AROUND LEFT TURNER	OTHER	AROUND LEFT TURNER	OTHER		LEFT TO RIGHT	RIGHT TO LEFT	FROM LEFT	FROM RIGHT										

1 = Routine; * = Moderate; ⊛ = Severe

Figure G2. Conflict Data Sheet: Unsignalized Intersections.

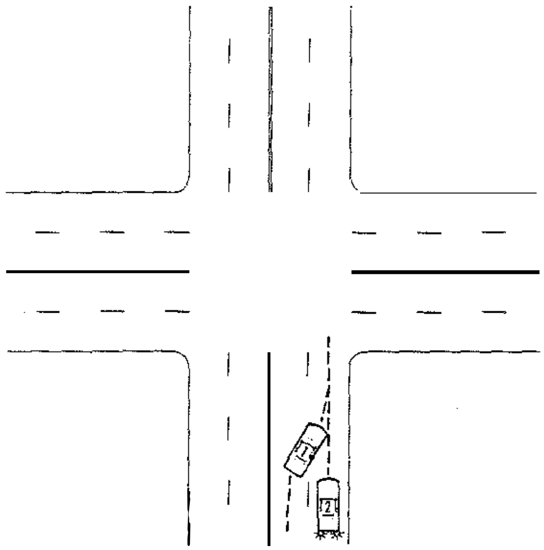

Figure G3. Weave Conflict.

There are a number of special events which are not listed on the conflict data sheets. These include 6 weave types, 13 conflict types, and 26 types of erratic maneuvers; these are given in Table G1. Observers should be familiar with these categories of events and should carry a copy of this listing during all conflict surveys. Whenever one of these special events is observed, the letter corresponding to the event should be marked under one of the blank columns on the conflict data sheet. If one special event is observed with some regularity at a site, a column can be designated to count such events.

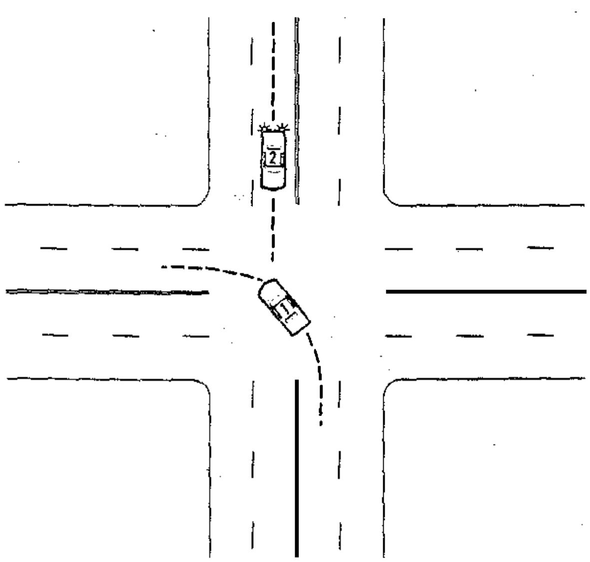

Figure G4. Opposing-Left-Turn Conflict.

Table G1. Other Traffic Events.

WEAVES	
A	Weave for stopped truck
B	Weave for stalled vehicle
C	Weave for stopped bus
D	Weave for road maintenance or construction
E	Weave to avoid pedestrian
F	Weave into turn lane and back into major traffic flow
CONFLICTS	
G	Conflict due to erratic maneuver
H	Slow for turn out of driveway or shopping entrance
I	Slow for turn into driveway or shopping entrance
J	Driveway cross traffic from left
K	Driveway cross traffic from right
L	Slow for stopped bus
M	Slow for road maintenance or construction
N	Slow for stopped truck
O	Weave pedestrian conflict
P	Previous conflict due to pedestrian (following car)
Q	Right turn on red without stop
R	Left-lane vehicle slow for right turner
S	Slow or stop for stalled vehicle
ERRATIC MANEUVERS	
T	Left turn from wrong lane
U	Right turn from wrong lane
V	U-turn in road
W	Use of shoulder for turns
X	Right-turner hitting curb
Y	Vehicles overrunning stop bar and backing up
Z	Vehicle backing from driveway across traffic lanes
AA	Turn into wrong lane (opposing lane)
BB	Stop in median
CC	Run off road
DD	Right-turn-on-red without stopping
EE	Late-entry right turn (or non-use of turn lane)
FF	Late-entry left turn (or non-use of turn lane)
GG	Vehicle unexpectedly stopped in road
HH	Vehicle swerve across traffic lanes
II	Vehicle backing in road
JJ	Turn into turn lane and back into traffic flow
KK	Vehicle on wrong side of road
LL	Wide turn (encroaching into adjacent lane)
MM	Multiple vehicle erratic maneuver
NN	Multiple bicycle erratic maneuver
OO	Bicycle on wrong side of road
PP	Bicycle riding in median
QQ	Illegal pedestrian crossings

Slowed-for-Right-Turn

The slowed-for-right-turn conflict is a situation in which a vehicle slows and turns from a traffic lane used by through traffic while being followed by a through vehicle. As Vehicles 1 and 2 approach the intersection as a pair, Vehicle 1 slows to turn right from a lane used by through traffic; through Vehicle 2 brakes to avoid Vehicle 1 -- the criterion of the conflict (Figure G5).

Slowed-for-Left-Turn

A slowed-for-left-turn conflict occurs when a leading vehicle, followed closely by a second vehicle, approach an intersection in a lane shared by through and left-turn vehicles. The first slows or stops to turn left; and the second, a through vehicle, brakes to avoid the slowing, turning vehicle.

Previous-Left-Turn Conflict

This type of conflict only occurs after a slowed-for-left-turn conflict. The first vehicle which slows or stops behind a left-turning vehicle is counted as a slowed-for-left-turn conflict, as stated above. If one or more other vehicles must also slow or stop for the same left-turner, then one previous-left-turn conflict is counted, regardless of the number of slowing vehicles. For any conflict count period, the number of slowed-for-left-turn conflicts must equal or exceed the number of previous-left-turn conflicts.

Other Previous Conflicts

Other previous conflicts occur when one or more vehicles break to avoid collision shortly after another conflict. An example of another previous conflict is shown in Figure G6 when Vehicle 2 slows to avoid Vehicle 1 which was involved in an opposing-left-turn conflict.

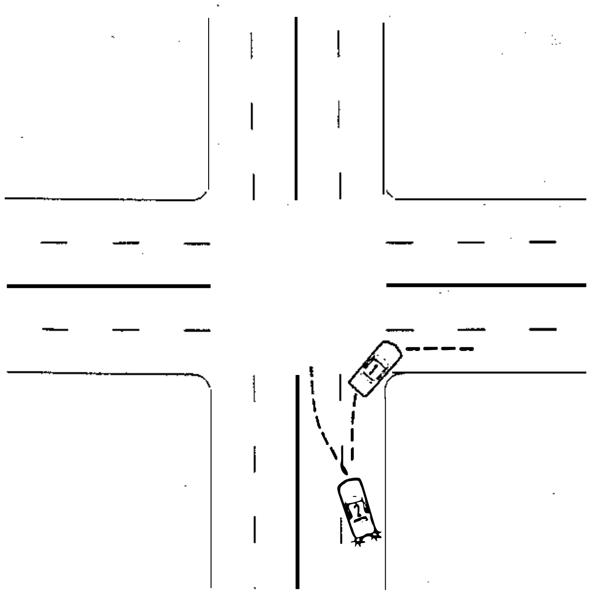

Figure G5. Slowed-for-Right-Turn Conflict.

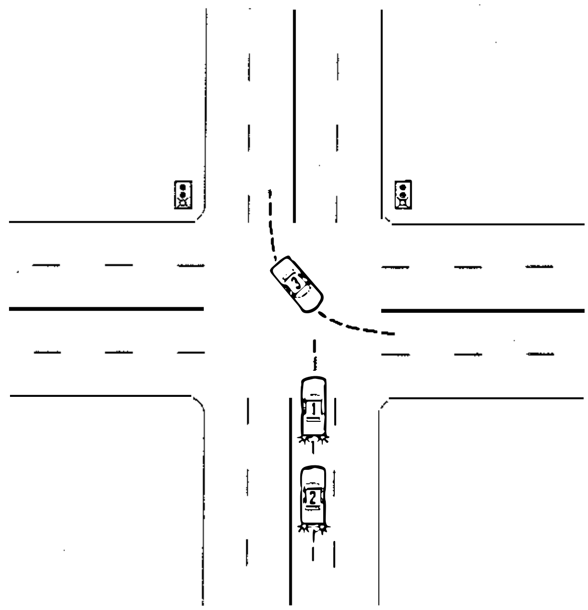

Figure G6. Previous Traffic Conflict.

Traffic-Backup or Congestion Conflict

This occurs when a vehicle approaches an intersection on a green light and must slow or stop due to other vehicles backed up. Another cause of this conflict is where vehicles on the side street block the intersection, causing vehicles on the observed approach to brake. One conflict is counted per lane during the green phase for each event, regardless of the number of vehicles which brake. One exception is where two separate groups of vehicles (separated by a long gap) pass the intersection during the same green signal phase and when backup conflicts occur during each (independently of the other). No conflicts are counted for vehicles slowing or stopping during the yellow or red lights.

Slow-Moving-Vehicle Conflict

A slow-moving-vehicle conflict occurs when a vehicle slows or stops in a through lane on the green light and causes a following vehicle to brake (Figure G7).

Pedestrian Conflict

This occurs when a single vehicle slows to avoid a pedestrian crossing the street.

Of the weave and conflict categories defined for signalized intersections, most of them also apply to nonsignalized intersections. However, there are several categories which apply only to nonsignalized intersections.

Through-Cross-Traffic

The through-cross-traffic conflict occurs when a through, side-street vehicle crosses the path of a through,

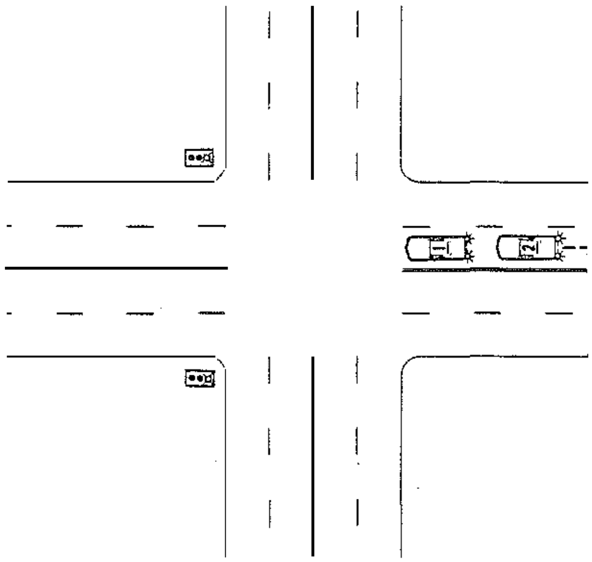

Figure G7. Slow-Moving-Vehicle Conflict.

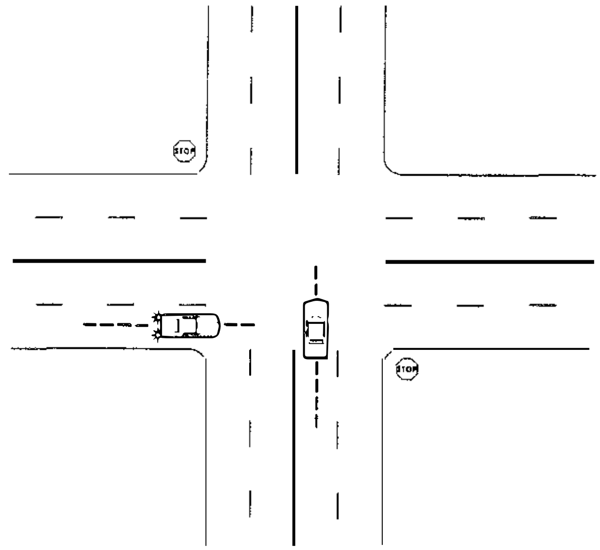

Figure G8. Through-Cross-Traffic Conflict from Right.

right-of-way vehicle, causing the right-of-way vehicle to brake. Conflicts are initiated by cross-road vehicles approaching from the right (Figure G8) or left.

Left-Turn-Cross-Traffic

A left-turn-cross-traffic conflict occurs when a side street vehicle turns left across the path of the through, right-of-way vehicle, causing the right-of-way vehicle to brake. Conflicts are initiated by side-street vehicles turning left from the left or right.

Right-Turn-Cross-Traffic

A right-turn-cross-traffic conflict occurs when a side-street vehicle, approaching from the right, turns right into the path of a through, right-of-way vehicle and causes the right-of-way vehicle to brake. This type of conflict may also occur at signalized intersections, but it is not included as a major category on the signalized intersection data sheet because they occur so infrequently at such locations.

All conflicts should be designated by the observer as either routine, moderate, or severe. A routine conflict is usually characterized by normal brakelights where there is no real danger of collision. A large majority of conflicts at most intersections are routine. Moderate conflicts involve quick decelerations and situations where some urgency was noted in a driver's reaction (all abrupt stops are moderate conflicts). A severe conflict (near-miss accident) is where a collision is barely avoided due to a last-second movement or stop. Symbols used for recording routine, moderate, and severe conflicts are noted on the data sheets.

INTERSECTION CONFLICT DATA SHEET

LOCATION ______________________________ DATE ______________

APPROACH ______________________ OBSERVER ______________________

STARTING TIME		TRAFFIC BACKUP OR CON-GESTION	OPPOSING LEFT TURN	SLOW FOR RIGHT TURN	SLOW FOR LEFT TURN	WEAVE CONFLICT		SLOW MOVING VEHICLE	THROUGH CROSS TRAFFIC		LEFT TURN CROSS TRAFFIC		RIGHT TURN CROSS TRAFFIC	PEDESTRIAN CONFLICT	OTHER (LIST BELOW)	VOLUME
						AROUND LEFT TURNER	OTHER		LEFT TO RIGHT	RIGHT TO LEFT	FROM LEFT	FROM RIGHT				
	C															LT- ST-
	S C															RT-
	C															LT- ST-
	S C															RT-
	C															LT- ST-
	S C															RT-
	C															LT - ST-
	S C															RT-
	C															LT- ST-
	S C															RT-
	C															LT- ST-
	S C															RT-

OTHER CONFLICT TYPES

A - Right turn cross traffic, from left
B - Bicycle
C - Opposing right-turn-on-red
D - Opposing LT-RT
E - Rear end, vehicle backing
F - Opposite both straight
G - Left turn from wrong lane
H - Right turn from wrong lane
I - Other (Explain)

SINGLE VEHICLE

J - Ran red light (LT)
K - Ran red light (ST-RT)
L - RTOR-LTOR did not stop
M - Abrupt stop

C - Conflict SC - Secondary Conflict

SEVERITY

I-Routine +- Moderate *-Severe

ADJACENT DRIVEWAY

N - Entering
O - Exiting

COMMENTS ______________________________
____
____

Figure G9. Revised Intersection Conflict Data Sheet.

Appendix H.

SUGGESTED CORRECTIONS FOR HAZARDOUS LOCATIONS

Based on eight specific types of accidents, the following listing was developed for suggested corrections for hazardous locations (14). This listing is a guide for use by traffic engineers to help select improvements that will reduce specific accident types.

Right-Angle and Rear-End Collisions at Intersections

1. Removal of view obstructions, such as foliage, bushes, billboards, or parking at curb.
2. Installation of warning signs, if speeds are high and the element of surprise is present.
3. Installation of stop signs, if view is obstructed to such an extent that safe approach speed is 8 miles per hour (3.6 m/s) or less, if one street is an approach street, or if no other remedy reduces accident frequency.
4. Installation of traffic signals if minimum warrants are met.
5. Continuing operation of traffic signals during certain light-traffic hours when signals are normally off.
6. Provision of proper clearance interval in signal cycle.
7. Relocation, repair, or other means of providing better visibility of signs or signals.
8. Better street lighting.
9. Provision of pedestrian crosswalk markings and(or) pedestrian barriers.
10. Rerouting of through traffic onto specially designated and protected through streets.
11. Creation of one-way streets.
12. Provision of traffic signal system time for progressive movement.
13. Speed zoning to safe approach speed.

Head-On, Left-Turn Collisions at Intersections

1. Provision of turning guidelines.
2. Prohibition of left turns (provided such movement is of little importance).
3. Provision of channelizing islands.
4. Provision of protected turning interval, via traffic signal control.
5. Installation of STOP signs (provided no other remedy works).
6. Elimination of view obstructions.
7. Creation of one-way streets.
8. Routing of turning traffic via an alternate route (with proper signs) to eliminate left turns.

Pedestrian-Vehicular Collisions at Intersections

1. Installation of pedestrian crosswalk lines.
2. Erection of pedestrian barriers.
3. Installation of traffic signals.
4. Provision of pedestrian refuge islands.
5. Prohibition of curb parking.
6. Provision of adequate street lighting.

7. Creation of one-way streets.
8. Rerouting of through traffic to specially designated and protected through streets.
9. Addition of pedestrian indications and pedestrian actuation features to existing traffic signals.

Sideswipe Collisions

1. Installation of painted pavement lane lines.
2. Installation of channelizing islands at intersections.
3. Installation of advance warning signs to warn drivers of proper lane for certain destinations.
4. Speed zoning.
5. Provision of acceleration or deceleration lanes at intersections.
6. Widening of pavement.
7. Creation of one-way streets.
8. Elimination of marginal obstructions caused by parked vehicles or other bottlenecks.

Head-On Collisions

1. Same remedies as for sideswipe collisions.
2. Installation of "no passing" zones at curves or other points with restricted view.
3. Installation of center dividing strip.

Vehicles Running Off Roadway

1. Installation of pavement centerline.
2. Installation of warning reflectors, guardrail, or white posts at curves.
3. Installation of advance warning signs.
4. Installation of roadside delineators.
5. Speed zoning.
6. Street lighting.
7. Skidproofing slippery pavements, improving shoulder maintenance, and prompt ice treatment and snow removal.

Collision with Fixed Objects

1. Application of paint and reflectors to fixed object.
2. Use of pavement guidelines to guide traffic around obstruction.
3. Street lighting.
4. Reduction of the number of fixed objects.
   a. Place necessary signs in the median, back-to-back wherever possible.
   b. Remove unnecessary sign posts (consolidate signs).
   c. Combine signs and light poles where possible.
   d. Utilize existing structures for posting signs.
   e. Use sign bridges where possible rather than gore signs.
5. Reduction of exposure to fixed objects.
   a. Place signs and light poles on the right side of pavements rather than in the median or gore areas, reducing exposure to total traffic.

b. Use sign bridges where possible rather than gore signs.

6. Minimizing hazards of fixed objects.
   a. Provide guardrail in front of fixed objects.
   b. Use prows and other methods wherever guardrail is not suitable.
   c. Use breakaway sign supports and light poles.

Collisions with Parked Cars

1. Parking prohibitions.
2. Change from angle to parallel parking.
3. Rerouting of through traffic to less congested, specially protected through streets.
4. Creation of one-way streets.

Appendix I.

DYNAMIC PROGRAMMING SOURCE DECK

```
C    DATE:  AUGUST 5,1974
C    PROGRAMMER:  THIS PROGRAM WAS WRITTEN BY JESSE MAYES, DIVISION OF
C    RESEARCH, DEPT. OF TRANS.,COMMONWEALTH OF KY.,533 S. LIMESTONE ST.,
C    LEXINGTON, KY.  PARTS OF THE PROGRAM,INCLUDING THE DYNAMIC
C    PROGRAMMING ALGORITHUM, HAVE BEEN ADAPTED FROM A PROGRAM WRITTEN BY
C    THE STATE OF ALABAMA HIGHWAY DEPT., BUREAU OF MAINT., 1973.  SEE
C    REPORT "CORRECT: COST/BENEFIT OPTIMIZATION FOR THE REDUCTION OF ROAD
C    ENVIRONMENT CAUSED TRAGEDIES".
C    PURPOSE:  THIS PROGRAM CALCULATES COSTS AND BENEFITS FOR EACH
C    ALTERNATIVE AT EACH LOCATION THEN DETERMINES THE OPTIMAL SOLUTION
C    SET OF ALTERNATIVES TO BE IMPLEMENTED FOR A GIVEN RANGE OF BUDGETS.
C    INPUT AND OUTPUT:  SEE DIVISION OF RESEARCH REPORT: "OPTIMAL HIGHWAY
C    SAFETY IMPROVEMENTS BY DYNAMIC PROGRAMMING".
      DIMENSION TITL(20),XLOC(90,10),NDE(90),C(90,11),B(90,11),LOC(90)
      DIMENSION ORET(90,501),NOD(90,501)
      NINP = 501
      NLOC = 90
C    NINP = NUMBER OF INCREMENTS---MAXIMUM BUDGET EQUALS NINP*XINC
C    NLOC = MAXIMUM NUMBER OF LOCATIONS
      INN = 13
      IOUTPR = 3
C    INN,IOUTPR = LOCAL INPUT AND OUTPUT DEVICE NUMBERS
      READ(INN,1000) TITL
 1000 FORMAT(20A4)
      WRITE(IOUTPR,1010) TITL
 1010 FORMAT (20X,20A4/////)
      READ(INN,2000) NSTG,BUDGET,PRTSTR,PRTINC,IOUTCB
 2000 FORMAT(T1,I4,T11,3F10.0,T41,I5)
      IF(IOUTCB.NE.0) IOUTCB=8
      IF(IOUTCB.EQ.0) IOUTCB=IOUTPR
      I=NINP-1
      IX=BUDGET/I + .5
      XINC=IX
      K1=PRTSTR/IX +.01+ 1
      K2=PRTINC/IX +.01
      CALL COSBEN(C,B,XLOC,LOC,NDE,NSTG,NLOC,XINC,INN,IOUTCB,KIK)
      IF(KIK.EQ.1) GO TO 10
      CALL DYNAM(C,B,LOC,XLOC,NDE,NSTG,XINC,K1,K2,NINP,NLOC,
     + ORET,NOD,IOUTPR)
   10 CONTINUE
      CALL EXIT
      END
      SUBROUTINE COSBEN(PWC,PWB,XLOC,LOC,NDE,NSTG,NLOC,XINC,INN,IOUTPR,
     + KIK)
C    THIS SUBROUTINE CALCULATES PRESENT WORTH COSTS AND BENEFITS
C    ASSOCIATED WITH EACH ALTERNATIVE AT EACH LOCATION
      DIMENSION XLOC(NLOC,5),SEV(8,4),CSEF(10,11),B(8),
     + NDE(NLOC),PWC(NLOC,11),PWB(NLOC,11),LOC(NLOC)
      READ(INN,1000) CFAT,CINJ,CPDO,RATEIN,RATEGR
 1000 FORMAT (8F10.0)
      WRITE(IOUTPR,1010) CFAT,CINJ,CPDO,RATEIN,RATEGR
 1010 FORMAT(' NEG UTILITY FATALITY=',F7.0,'  INJURY=',F6.0,'  PRP DM='
     +,F5.0//' INTEREST RATE = ',F5.3/' EXPONENTIAL GROWTH RATE = ',F5.3/
     +////)
C    THE ABOVE READS AND PRINTS THE BASIC PARAMETERS CONSTANT FOR THE
C    ENTIRE PROGRAM
      NUMBER = 1
      KIK = 0
C     BELOW IS THE INPUT WHICH IS EXECUTED FOR EACH ACCIDENT LOCATION.
   10 READ(INN,1020) NO1,(XLOC(NUMBER,I),I=1,10),TIME,NMO,NYR,NCAU
 1020  FORMAT(I4,10A4,27X,   F4.0,I2,I2,I1)
      LOC(NUMBER) = NO1
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      IF(NO1)20,180,20
   20 CONTINUE
      WRITE(IOUTPR,1030)
 1030 FORMAT(1H1)
      WRITE(IOUTPR,1040)
 1040 FORMAT(' REF NO')
      IF(NCAU.EQ.1) GO TO 30
      WRITE(IOUTPR,1050) NO1,(XLOC(NUMBER,I),I=1,5),TIME,NMO,NYR,NCAU
 1050 FORMAT(3X,I4,8X,5A4,//9X,'ACCIDENT HISTORY ',F5.2,
     + 'YEARS.  MONTH ',I2,',YEAR ',I2,', ',I1,' CAUSE. ')
      GO TO 40
   30 WRITE(IOUTPR,1060) NO1,(XLOC(NUMBER,I),I=1,5),TIME,NMO,NYR,NCAU
 1060  FORMAT(3X,I4,8X,5A4,//9X,'ACCIDENT HISTORY ',F4.2,
     +' YEARS.  MONTH ',I2,',YEAR ',I2,', ',I1,' CAUSE. ')
   40 CONTINUE
C     SECOND CARD INPUT FOR EACH CRITICAL LOCATION (SEVERITIES).
      READ(INN,1070)NO2,((SEV(I,J),J=1,4),I=1,NCAU),ALT
 1070 FORMAT(I4,1X,15F5.0)
      NALT=ALT + .5
      NDE(NUMBER) = NALT
C     ROUTINE TO CHECK CARD SEQUENCE CODE.
      IF(NO1-NO2) 50,60,50
   50 WRITE(IOUTPR,1080)NO1,NO2
 1080 FORMAT('  SEQUENCE/CODE NO. ERROR. CHECK ',I5,' AND',I5,
     +' **EXECUTION TERMINATED')
      KIK = 1
      GO TO 190
   60 CONTINUE
C     OUTPUT OF SEVERITIES AND TOTALS.
      WRITE(IOUTPR,1090)
 1090 FORMAT(/ ' ROADWAY                  NO.     NO.        NO.'/,
     +           ' CAUSE                  KILLED  INJURED    PDO')
      TOT1=0
      TOT2=0
      TOT3=0
      TOT4=0
      DO 80 I=1,NCAU
      WRITE(IOUTPR,1100) I,(SEV(I,J),J=2,4)
 1100 FORMAT (1X,I7,12X,3F8.0)
   70 CONTINUE
      TOT1=TOT1+ SEV(I,1)
      TOT2=TOT2+ SEV(I,2)
      TOT3=TOT3+ SEV(I,3)
      TOT4=TOT4+ SEV(I,4)
   80 CONTINUE
      WRITE(IOUTPR,1110) TOT1,TOT2,TOT3,TOT4
 1110 FORMAT('  TOTALS',12X,3F8.0)
C     INPUT NEXT SET OF NALT CARDS, ONE FOR EACH ALTERNATIVE
      NJ=3+NCAU
      DO 110  I=1,NALT
      READ(INN,1120) NO3,(CSEF(I,J), J=1,NJ)
 1120 FORMAT(I4,F8.0,F2.0,F6.0,8F5.2)
      IF(NO3-NO1)90,100,90
   90 WRITE(IOUTPR,1080) NO1, NO3
      KIK = 1
      GO TO 190
  100 CONTINUE
  110 CONTINUE
C     OUTPUT OF ALTERNATIVE INFORMATION.
      WRITE(IOUTPR,1130)(I,I=1,NCAU)
 1130 FORMAT(/' ALTERNATIVE    COST   LIFE   MAIN COST   EFFECT ON...',
     +8I5)
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C    NUMBER COUNT CHECK OF SEVERITIES.
        DO 120 I=1,NALT
        WRITE(IOUTPR,1140) I,(CSEF(I,J),J=1,NJ)
 1140 FORMAT(I7,F13.0,F8.0,F9.0,19X,8F6.2)
  120 CONTINUE
C    COMPUTATION OF B(I), THE ITH ALTERNATIVE BENEFIT.
        DO 140  I=1,NALT
        B(I) = 0.
        DO 130 J=1,NCAU
        JEFT = J +3
        B(I) = B(I) + (CFAT*SEV(J,2)+CINJ*SEV(J,3)+CPDO*SEV(J,4))*
       + CSEF(I,JEFT)
  130 CONTINUE
  140 CONTINUE
C    CALCULATION OF BENEFIT/COSTS AND OUTPUT.
        DO 150 I=1,NALT
        B(I)=B(I)*CSEF(I,2)/TIME
        BNCS = B(I)/CSEF(I,1)
  150 CONTINUE
        WRITE(IOUTPR,1170)
 1170 FORMAT(  ////'   BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED'/)
        WRITE(IOUTPR,1210)
        DO 160 I=1,NALT
        XMAIN=CSEF(I,2)*CSEF(I,3)
        BENM=B(I)-MAINT
        BNCM=BENM/CSEF(I,1)
        WRITE(IOUTPR,1220) I,XMAIN,CSEF(I,1),BENM,BNCM
  160 CONTINUE
        WRITE(IOUTPR,1200)
 1200 FORMAT(  ////'   BENEFIT/COST ANALYSIS, MAINTENANCE INCLUDED ***PRE
       +SENT WORTH METHOD***'/)
        WRITE(IOUTPR,1210)
 1210 FORMAT(' ALTERNATIVE        MAINTENANCE          COST       BENEFIT
       + BENEFIT/COST')
        DO 170 I=1,NALT
        LIFE = CSEF(I,2)
        X = (1.+RATEIN)**LIFE
        PWF = (X-1.)/(RATEIN*X)
        Y = (1.+RATEGR)/(1.+RATEIN)
        PWEXGR = (Y**(LIFE+1)-1.)/(Y-1.) - 1
        PWC(NUMBER,1) = 0
        PWB(NUMBER,1) = 0
        PWMAIN = PWF*CSEF(I,3)
        PWC(NUMBER,I+1) = CSEF(I,1)
        PWB(NUMBER,I+1) = PWEXGR*B(I)/LIFE - PWMAIN
        PWBC = PWB(NUMBER,I+1)/PWC(NUMBER,I+1)
        WRITE(IOUTPR,1220) I,PWMAIN,PWC(NUMBER,I+1),PWB(NUMBER,I+1),PWBC
 1220 FORMAT(I7,F23.2,F14.2,F11.2,5X,F11.2)
  170 CONTINUE
        NUMBER = NUMBER + 1
        GO TO 10
  180 CONTINUE
        NUMBER = NUMBER - 1
        IF(NUMBER.EQ.NSTG) GO TO 190
        WRITE(IOUTPR,1230)
 1230 FORMAT('1',40('*'),'  WARNING  ',40('*')//)
        WRITE(IOUTPR,1240) NUMBER,NSTG
 1240 FORMAT(' ','NUMBER OF LOCATIONS READ = ',I3/' ','NUMBER OF LOCATIO
       +NS EXPECTED = ',I3)
  190 CONTINUE
        RETURN
        END
```

```
      SUBROUTINE DYNAM(C,B,LOC,XLOC,NDE,NSTG,XINC,K1,K2,NINP,NLOC,
     + ORET,NOD,IOUTPR)
C     THIS SUBROUTINE USES "DYNAMIC PROGRAMMING" TO FIND THE OPTIMAL
C     SOLUTION SET ALTERNATIVES (ONE AT EACH LOCATION) GIVEN COSTS,
C     BENEFITS AND A RANGE OF BUDGETS.  THE ALGORITHUM IS BASED ON WORK BY
C     RICHARD BELLMAN (DYNAMIC PROGRAMMING,1957)
      DIMENSION ORET(NLOC,NINP),NOD(NLOC,NINP),NDE(NLOC),
     + C(NLOC,11),B(NLOC,11),R(11),XLOC(NLOC,5),LOC(NLOC)
C     THESE DIMENSIONS MUST BE AT LEAST AS BIG AS THE NUMBER OF LOCATIONS
      DIMENSION CC(200),BB(200),AA(200),BC(200),LL(200),KKK(200)
      IST=0
      VRET=0.0
      WRITE(IOUTPR,1130)
      WRITE(IOUTPR,1000)
 1000 FORMAT(' ',40('*'),'PARAMETER VALUES',40('*')////)
      WRITE(IOUTPR,1010)
 1010 FORMAT(' ',27X,18('-'),'OUTPUT',18('-'))
      WRITE(IOUTPR,1020) NSTG,XINC,K1,K2
 1020 FORMAT(5X,'LOCATIONS---INCREMENT---LOWER LIMIT---INCREMENTS PER ST
     +EP',/,3X,I9,3X,F12.2,I9,10X,I9,//,'-----LOCATION---ALTERNATIVES')
      DO 10 I=1,NSTG
      WRITE(IOUTPR,1030) LOC(I),NDE(I)
 1030 FORMAT(7X,I5,I10)
   10 CONTINUE
      WRITE(IOUTPR,1040)
 1040 FORMAT('1',30('*'),'LOCATIONS,ALTERNATIVES,COSTS AND BENEFITS',
     + 30('*')////)
      WRITE(IOUTPR,1050)
 1050 FORMAT (1H ,'--LOCATION---LOCATION NAME',28('-'),'ALT-NUM--------C
     +OST-----RETURN-----B/C RATIO')
C     FIND THE OPTIMAL ALTERNATIVE AT THE I-TH LOCATION WITH J INCREMENTS
C     AVAILABLE
      DO 140 I=1,NSTG
      NDEC=NDE(I)+1
      R(1)=0.
      DO 20 IC=2,NDEC
   20 R(IC) = B(I,IC)
      DO 30 IC=2,NDEC
      ICM1 = IC-1
      BCRAT = R(IC)/C(I,IC)
      IF(IC.EQ.2) AA(I)=BCRAT
      WRITE(IOUTPR,1060) LOC(I),(XLOC(I,J),J=1,10),ICM1,C(I,IC),R(IC),
     +  BCRAT
 1060 FORMAT(I9,5X,10A4,I6,3X,F11.0,F11.0,4X,F10.2,F15.0,F15.0)
   30 CONTINUE
 1070 FORMAT(8F10.0)
      DO 130 J=1,NINP
C     INCREMENT BUDGET
      XIN=(J-1)*XINC
      DUM=-1000000000000.
      NDEC=NDE(I)+1
C     DETERMINE THE BEST ALTERNATIVE--NOD(I,J)--AT I-TH LOCATION GIVEN
C     J-1 INCREMENTS TO SPEND ON LOCATION 1 THRU LOCATION I-----YIELDING
C     A RETURN OF--ORET(I,J)--
      DO 120 K=1,NDEC
      CALL XOUT(I,IST,XIN,K,KICK,XINC,C,NLOC)
      IF(KICK)50,50,40
   40 GO TO 120
   50 CONTINUE
      IF(I-1)60,60,70
   60 TEST=R(K)
      GO TO 80
```

```
   70 TEST=R(K)+ORET(I-1,IST)
      GO TO 80
   80 IF((DUM-TEST))90,100,100
   90 DUM=TEST
      ORET(I,J)=DUM
      NOD(I,J)=K
  100 GO TO 110
  110 CONTINUE
  120 CONTINUE
  130 CONTINUE
  140 CONTINUE
      CALL DATORD(AA,LL,NSTG)
      WRITE(IOUTPR,1049)
 1049 FORMAT('1',25('*'),'LOCATIONS,ALTERNATIVES,COSTS, AND BENEFITS-',
     + 'ORDERED BY BENEFIT/COST RATIO',
     + 25('*')//)
      WRITE(IOUTPR,1051)
 1051 FORMAT (1H ,'--LOCATION---LOCATION NAME',28('-'),'ALT-NUM--------C
     +OST-----RETURN-----B/C RATIO-----ACCUM COST--ACCUM RETURN')
      TOTRTN=0
      TOTCST=0
      DO 149 II=1,NSTG
      I=LL(II)
      IC=2
      ICM1=IC-1
      R(IC)=B(I,IC)
      TOTRTN=TOTRTN+R(IC)
      TOTCST=TOTCST+C(I,IC)
      WRITE(IOUTPR,1060) LOC(I),(XLOC(I,J),J=1,10),ICM1,C(I,IC),R(IC),
     + AA(II),TOTCST,TOTRTN
  149 CONTINUE
 1061 FORMAT('1')
      WRITE(IOUTPR,1061)
      IPAGE = 0
C     WRITE MAIN BUDGET OUTPUT HEADING
      WRITE(IOUTPR,1080)
 1080 FORMAT('1',90('*')//' ',37('*'),' BUDGET  OUTPUT ',37('*')//' ',
     + 90('*')/////)
      DO 160 M=K1,NINP,K2
      J=M
      XIN=(J-1)*XINC
      BUDG=XIN
      IPAGE = IPAGE + 1
      IF(IPAGE.NE.1) WRITE(IOUTPR,1130)
C     WRITE INDIVIDUAL BUDGET OUTPUT HEADING
      WRITE(IOUTPR,1290) BUDG
 1290 FORMAT('0',15X,'BUDGET = ',F12.0,/)
      WRITE(IOUTPR,1090)
 1090 FORMAT(' ',        15X,'BUDGET  LOCATION =',4X,'LOCATION NAME
     + ',4X,'ALT-NUM',5X,'COST',6X,'RETURN',4X,'ACCUM RETURN')
 1100 FORMAT('0',6X,F15.2)
      TOTCST = 0
      TOTRTN = 0
      DO 150 L=1,NSTG
      I=NSTG+1-L
      K=NOD(I,J)
      KKK(I)=K
      CC(I)=C(I,K)
      BB(I)=B(I,K)
      CALL XOUT(I,IST,XIN,K,KICK,XINC,C,NLOC)
      J=IST
      XIN = XIN-C(I,K)
```

```
      150 CONTINUE
          DO 155 I=1,NSTG
          K=KKK(I)
          KK=K-1
          TOTRTN = TOTRTN + BB(I)
          TOTCST = TOTCST + CC(I)
          BC(I)=0
          IF(CC(I).GT..01) BC(I)=BB(I)/CC(I)
          AA(I)=BC(I)
C     WRITE I-TH LOCATION INFORMATION---TOTAL BUDGET OF M INCREMENTS
          WRITE(IOUTPR,1110) LOC(I),(XLOC(I,JJ),JJ=1,10),KK,CC(I),BB(I),
         & TOTRTN
     1110 FORMAT(' ', 4X,I4,9X,10A4,5X,I4,2F12.0,4X,F12.0)
      155 CONTINUE
C     WRITE TOTALS
          WRITE(IOUTPR,1120) TOTCST,TOTRTN,TOTRTN
     1120 FORMAT('0',29('*'),' TOTALS ',29('*'),2F12.0,4X,F12.0)
          WRITE(IOUTPR,1140)
     1140 FORMAT('1','LISTING OF SELECTED PROJECTS BY B/C RATIO')
          WRITE(IOUTPR,1091)
     1091 FORMAT(' ',        15X,'BUDGET  LOCATION =',4X,'LOCATION NAME
         + ',4X,'ALT-NUM',5X,'COST',6X,'RETURN',4X,'ACCUM RETURN',
         &9X,'B/C',2X,'ACCUM B/C')
          WRITE(IOUTPR,1100) BUDG
          CALL DATORD(AA,LL,NSTG)
          TOTRTN=0
          TOTCST=0
          DO 190 II=1,NSTG
          I=LL(II)
          K=KKK(I)
          KK=K-1
          IF(BB(I).LT.1.0) GO TO 195
          TOTRTN=TOTRTN+BB(I)
          TOTCST=TOTCST+CC(I)
          ACCBC=TOTRTN/TOTCST
          WRITE(IOUTPR,1111) LOC(I),(XLOC(I,JJ),JJ=1,10),KK,CC(I),BB(I),
         & TOTRTN,BC(I),ACCBC
     1111 FORMAT(' ', 4X,I4,9X,10A4,5X,I4,2F12.0,4X,F12.0,2X,F10.2,F10.2)
      190 CONTINUE
      195 CONTINUE
          WRITE(IOUTPR,1121) TOTCST,TOTRTN,TOTRTN,ACCBC
     1121 FORMAT('0',29('*'),' TOTALS ',29('*'),2F12.0,4X,F12.0,12X,F10.2)
      160 CONTINUE
      170 WRITE(IOUTPR,1130)
     1130 FORMAT('1')
      180 CONTINUE
          RETURN
          END
          SUBROUTINE XOUT(I,IST,XIN,K,KICK,XINC,C,NLOC)
C
C     THIS SUBROUTINE CALCULATES THE OUTPUT STATE NUMBER
C     RESULTING FROM THE INPUT XIN AND SAFETY MEASURE K.  IT
C     ALSO DETERMINES THE COST OF A PARTICULAR SAFETY MEASURE
C     CORRESPONDING TO STAGE I.
C
          DIMENSION C(NLOC,11)
          OUT=XIN-C(I,K)
          IF(OUT) 10,20,20
       10 KICK=1
          IST = 1
          GO TO 30
       20 KICK=0
```

```
      IST=(OUT/XINC) + 1.5
   30 RETURN
      END
      SUBROUTINE DATORD (D,L,M)
      DIMENSION D(M),L(M)
      DO 10 I=1,M
   10 L(I) = I
      DO 20 I=1,M
      IF(I.EQ.M) GO TO 20
      K = L(I)
      S = D(I)
      J1 = I
      DO 30 J=I,M
      IF(S.GE.D(J)) GO TO 30
      S = D(J)
      K = L(J)
      J1 = J
   30 CONTINUE
      D(J1) = D(I)
      D(I) = S
      L(J1) = L(I)
      L(I) = K
   20 CONTINUE
      RETURN
      END
```